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CEMENTED-CARBIDE TOOLS

CARBIDES AND BONDING AGENTS USED FOR METAL CUTTING, THE DESIGN, CARE AND MAINTENANCE OF TIPPED TOOLS.

by
D. H. SHUTE, B.Sc., (Eng.), A.R.S.M., A.I.M.M.

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PREFACE TO REVISED EDITION

Cemented-carbide tools have played an important part in armament production during the last war, and the technique of their application has become improved, extended and more understood. When the revision of this book was being considered, therefore, it was decided that to do justice to the subject mere revision methods would be inadequate, and steps were taken to have the whole book re-written. Whilst in a book of this size an exhaustive survey of carbide tooling is impossible, it is nevertheless hoped that all the more important points have been carefully presented to the practical man.

Those who were familiar with the book in its old form may find perhaps that the foci of interest have shifted somewhat—much matter hitherto deemed important being displaced by other aspects of the subject. In a constantly developing technique, this is unavoidable.

Although some years have now elapsed since the introduction of the hard carbides as cutting-tool materials, it would be unwise to say that the materials used, the shapes and angles of tools, and their applications have reached the stage whence no further change in development may be expected.

It will be noticed that scant reference is made to negative-rake cutting. This omission is due to the now fairly-established position of negative-rake cutting as a separate technique which is dealt with in a companion volume of the present publication.

With regard to the information contained in Chapter 6, we are grateful for the help freely given by the carbide manufacturers and suppliers.

THIS BOOK IS PRODUCED IN COMPLETE CONFORMITY WITH THE AUTHORIZED ECONOMY STANDARD

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CHAPTER 1

MANUFACTURE AND PROPERTIES OF CEMENTED CARBIDES

The history of the cemented carbide is an interesting example of a minor specialised investigation leading to the development of a material of major industrial importance. Osrams, the German lamp manufacturers, first introduced hard metal as a substitute for diamond wire-drawing dies used in the drawing of tungsten wire for electric-lamp filaments. Although the great hardness of carbides of such metals as tungsten had been known for many years, all efforts at producing dies from these carbides had met with failure. Various unsuccessful attempts had been made to form dies by casting tungsten carbide but they proved far too brittle in service. As the lamp manufacturers gained experience in the technique of powder metallurgy, tungsten wire, their main filament material, was worked up from powders. It was logical therefore for them to turn to this technique in making the drawing dies.

It had been known for some years that a hard tough alloy could be made by pressing a mixture of tungsten and nickel powders together in a hydraulic press and then heating the compact in a hydrogen atmosphere. A development from this was to use tungsten-carbide powder instead of tungsten powder mixed with nickel. Iron and cobalt could be used although cobalt was eventually found to be the most satisfactory metal. Thus a very good compromise had been struck between the extremely hard tungsten carbide and the softer tougher cobalt which acted as a binder for the hard carbide grains. This cemented carbide hard metal was quickly found not only to make excellent wire-drawing dies but also to be an exceptional material for machining cast iron, non-ferrous metals and such non-metallic substances as plastics and marble. The processing rights for this remarkable new alloy were taken over by Krupps of Essen and marketed in 1927 as Widia (a shortening of the German *Wie Diamant* = like a diamond).

When it became apparent that the straight tungsten carbide cobalt-mixtures were not completely suitable for the machining of steel, the search continued for new cutting alloys. The next important step came when it was found that the addition of titanium carbide to the tungsten carbide reduced the tendency to cratering. Hard metal containing titanium carbide came on to the market in 1931. Shortly after this two new compositions suitable for the machining of steel were announced, Titanit containing titanium carbide and molybdenum carbide bonded in nickel, and Ramet in which tantalum carbide partly replaced tungsten carbide.

From this time no startling new departures in composition or technique have been announced, apart from an interesting account of a method of preparing a compound of tungsten and titanium carbides in 1937 by McKenna. Progress has taken the form rather of a consolidation of the known processes resulting in greater control over, and uniformity of, the hard metal. A very large number of patents have been published since the original Krupps patents of 1927 although there is also a considerable patent literature on the refractory metals and carbides prior to 1927. Over 300 English patents alone have been granted since 1927 on cemented carbide.

Almost all of the higher melting point metals alone or in combination with other metals or borides, carbides, and silicides of these metals have been suggested as being capable of producing a suitable cutting tool. Undoubtedly many of the proposed alloys of boron, molybdenum, titanium, tungsten, uranium, zircon and the like will find an application in the engineering industry. In general, however, it may be said that most of the cemented carbide used to-day is made predominantly from tungsten, titanium, and tantalum carbides, usually with cobalt as the binder metal.

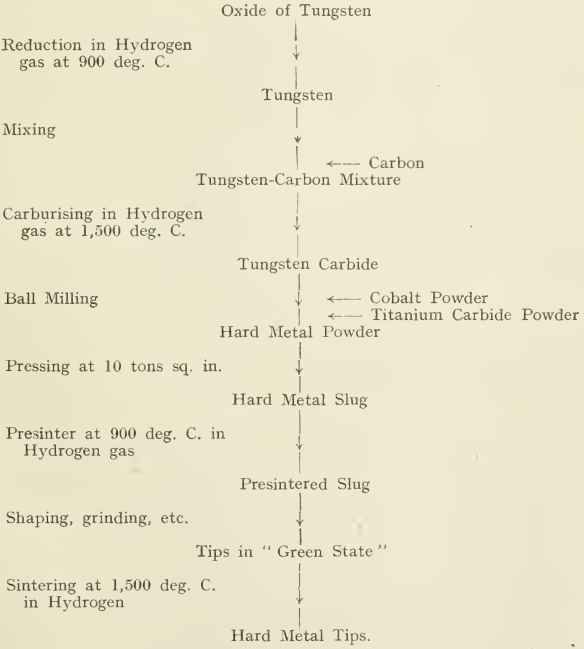
Several descriptions have been published in the past few years of different processes for manufacturing hard metal. The following outline of the process may be taken as typical.

Hard-carbide Tip Manufacture

The stages in the process may be better understood by referring to the flow diagram on page 7. Oxide of tungsten, a light-yellow powder, is heated in a stream of hydrogen gas at temperatures up to 950 deg. C. Oxygen from the tungstic oxide combines with the hydrogen forming water vapour and leaving grey dense tungsten, metal powder. This powder is mixed with carbon black and the mixture is heated to a temperature of 1500 deg. C. in a hydrogen atmosphere. The carbon combines with the tungsten forming tungsten carbide. Cobalt metal powder, usually produced in the same way as tungsten from cobalt oxide by hydrogen reduction, is now mixed with the tungsten carbide in ball mills for several days. Titanium carbide is also added at this stage if the hard metal powder is to be used for machining steel. The hard metal powder is then pressed into rectangular bars in suitable dies in a hydraulic press at a pressure of about 10 tons per sq. in. The hard metal slug is given a heat treatment, or presintering, at about 900 deg. C., in a hydrogen atmosphere. The presintered slug, which is still quite soft is next machined to the required shape and is then finally hardened by sintering at about 1500 deg. C. in an atmosphere of hydrogen.

Tips may also be pressed direct to shape from hard metal powder in a tabletting machine. This method of shaping is particularly useful in preparing a large quantity of tips of the same size.

One type of furnace used for the tungsten reduction consists of a long heat-resisting metal tube heated electrically or by gas. Oxide of tungsten is fed through the tube on narrow metal trays, whilst hydrogen gas is passed down the tube in the opposite direction to the trays. As the trays emerge from the heated zone of the furnace they pass into a water-cooled zone. When the trays are cool they are removed from the furnace and the tungsten metal powder is emptied into suitable containers. The rate of feeding the trays, rate of flow of gas, the temperature of the heated zones, and the raw material are all carefully controlled to ensure that a completely reduced tungsten of the required grain size is produced. After screening, the tungsten is mixed with carbon black in ball mills. The powder to be mixed and a charge of steel or tungsten carbide balls is placed in the mill, which consists of steel pot about 10 in. long and 9 in. diameter, and which is rotated about its horizontal axis by some suitable mechanism. By this method of mixing, intimate contact is ensured between the tungsten



Flow Diagram of the Manufacture of Hard-carbide Tool Tip

powder and carbon black. The mixed powder is subsequently heated in an electric furnace to 1500 deg. C. for about 3 hours.

Several different types of furnace are commonly employed in the industry. One type consists of an alumina tube round which a spiral of molybdenum tape is wound. The tube is placed in a rectangular tank in line with a feed tube and exit tube which are fixed at either end of the tank. Heating is effected by means of an electric current passed through the molybdenum spiral. Oxidation of the molybdenum is prevented by making the tank gas-tight and passing hydrogen gas through the tank, through the alumina tube and finally burning it at the end of the feed tube. The mixed tungsten and carbon is packed in graphite containers and it is then placed in the feed tube. The next container which is fed pushes the first container on into the heated alumina tube. As the feeding continues the containers are pushed in turn from the feed tube through the heated alumina tube to the cooling tube where they are removed from the furnace.

A similar type of furnace uses a carbon resistance tube through which a heavy current at low voltage is passed instead of the alumina tube with the molybdenum spiral. Heating by means of high-frequency currents may also be used.

Titanium carbide may be prepared by mixing the required amount of carbon black with titanium dioxide and heating the mixture in containers in a carbon resistance-tube furnace. A higher temperature, usually about 1,900 deg. C., is required for making titanium carbide than is needed for tungsten carbide. The tungsten carbide powder is mixed with cobalt powder in a ball mill, with the addition of titanium carbide if the powder is to be used for steel machining. This ball-milling operation, which usually takes several days, serves to break down the tungsten carbide into its individual grains and ensure a complete mixing of the constituents of the hard metal powder. After milling, the powder is mixed with about 1 per cent. of a lubricant such as paraffin wax dissolved in carbon tetrachloride and the waxed powder is now compacted in a suitable press. The powder may be pressed directly to the final shape or it can be pressed into some convenient form such as a rectangular block and shaped afterwards. A pressure of 10 tons/sq. in. is commonly used, although much lower pressures than this will produce a dense non-porous hard metal. After pressing to shape, the compacts are heated to about 900 deg. C. in a hydrogen atmosphere. This presintering, as it is called, renders the compact easily machinable, although not producing any appreciable increase in hardness.

The presintered hard metal, which has the consistency of chalk, is now machined by grinding or turning to the final shape of the hard metal. After final shaping the tips are packed in carbon or alumina powder in graphite trays and are fed through furnaces similar to those previously described for producing tungsten-carbide powder. This heat treatment causes the carbide particles to be sintered together by the

cobalt which partially liquifies and combines with the carbide grains. There is quite a considerable shrinkage, varying between 18 and 30 per cent depending on the powder, during the sintering, which must be allowed for when the tips are being machined in the presintered condition. Hard metal used for machining cast iron needs a sintering temperature of 1,450 deg. C., whilst steel-cutting qualities containing titanium carbide need a temperature about 100 deg. C. higher. Great care is necessary in sintering to see that the hydrogen gas is pure and extremely dry, that the graphite containers are in the furnace for the correct length of time and that the temperatures are accurately maintained. After sintering, the tips are inspected for hardness, density, size, etc.

Hot Pressing

There are many possible modifications of the process just described. For instance, the pressing and sintering stages may be carried out simultaneously, a process known as hot pressing. In this process the hard metal powder is placed in dies of a heat-resisting material, usually a dense form of block carbon or graphite. The dies are heated to a temperature similar to that used for sintering after cold pressing, *i.e.* around 1,400 deg. C. and pressure is applied at the same time. Heating of the carbon moulds may be either by electric resistance heating or by high-frequency induction heating. This hot-pressing process is of particular use for large masses of carbide such as ring dies.

Cemented carbide was extensively used during the war in armour-piercing projectiles, especially for use against tanks. The carbide nose of the shot was shaped liked a bullet, about 1 in. in diameter and $2\frac{1}{2}$ in. long, and pointed at one end. It is interesting to note that the Germans developed the technique of hot pressing for this application to a very high degree, incidentally an application for carbide on which the Germans had been actively working since 1929.

Instead of adding titanium carbide to the hard metal used for machining steel, mixed crystals of tungsten-titanium carbide are sometimes used. McKenna, for instance, uses a process which he claims produces a compound of the formula $WTiC_2$. This is prepared by heating tungsten, titanium dioxide and carbon with nickel in a graphite crucible in a high-frequency furnace. The mixture is heated up to a temperature of 2,100 deg. C., when the nickel melts forming a menstruum in which the other constituents dissolve. When the reaction between the tungsten, titanium dioxide and carbon are complete the melt is allowed to cool down. It is then crushed and treated with acid to remove the nickel. Further treatment removes impurities such as graphite. This double tungsten-titanium carbide is now ball-milled as usual with cobalt, tungsten and other constituents thus forming a hard metal powder. The process from this stage follows along normal lines.

A considerable degree of laboratory control is necessary at every stage in the process to ensure a satisfactory product of consistent quality.

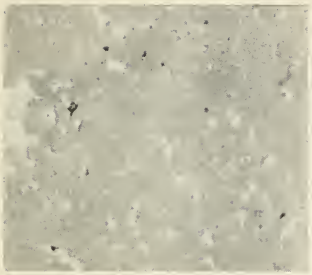
Careful chemical analysis and physical tests such as grain size measurements are commonly carried out on the powdered metals and carbides. Modern electronic devices such as the X-Ray diffraction camera and the electron microscope are also often used. Micro-examination of the cemented hard metals is also commonly carried out. One of the difficulties of micro-examination is the extremely fine grain size both of the process powders and the finished hard metal. The average grain size is of the order of 40/1000000 of an inch which is very near the limit of resolving power of the highest powered microscopes.

The micro-structure of a few typical types of hard metal are shown in Figs. 1-6. Figs. 1 and 2 show a straight tungsten-carbide/cobalt hard metal. The pools of cobalt may be clearly seen in Fig. 1 which is a photomicrograph of the polished specimen at a magnification of 1,500 diameters. Fig. 2 shows the same specimen at a magnification of 2,500 diameters with the surface etched to reveal more clearly the micro-structure. The angular grey areas are tungsten-carbide set in a white matrix of cobalt. Cemented carbide of this coarse grain size would not be suitable for use as a cutting tool, although it would be satisfactory as a deep drawing die where greater toughness is required. A more normal structure for a tungsten-carbide/cobalt mixture for use with a cutting tool is shown in Fig. 3. A still finer grained carbide is shown in Fig. 4. A micro-section of hard metal containing tantalum carbide is shown in Fig. 5. The different structure of cemented carbide which is suitable for steel machining is shown in Fig. 6. The chemical composition and the grain size of the cemented carbide may be altered to suit the machining operation. For instance, for general cast-iron machining, tungsten carbide with a 6 per cent of cobalt is often employed. A tool to be used for finish turning would contain about 4·5 per cent cobalt whilst a tool for intermittent cutting on cast-iron would probably contain more cobalt than the general-purpose tool and be made from a tungsten-carbide powder of coarser-grain size.

In machining materials such as cast iron which produce a soft crumbly or powdered chip, the straight tungsten-carbide/cobalt mixtures will be found to give the best results. As has been mentioned earlier, titanium carbide is added to the tungsten-carbide/cobalt mixture if the tool tip is to be used for steel machining in order to overcome the tendency to cratering at the position behind the cutting edge where the chip bears against the top face of the tool. It has been proved that the addition of titanium reduces the tendency of steel to weld on to the cemented carbide.

Physical Properties of Cemented Carbides

In general the cemented carbides combine the properties of great hardness with low shear and tensile strength. They have extremely high compressive strength and a Young's modulus greatly in excess of any other engineering material. The density varies from 14·8 gms./c.c. on the cast iron cutting qualities to 10·5 gm./c.c. for the titanium bearing carbides used for steel cutting. The toughness varies with the cobalt content, the higher the cobalt the tougher the carbide. The magnification of Figs. 3-6 is in each case 1,500 diameters.



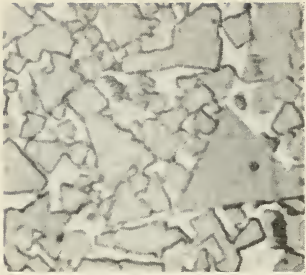
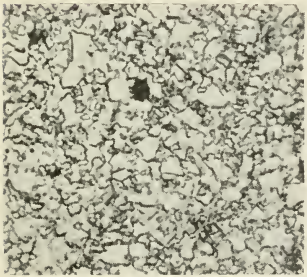


Fig. 1. (*Left*) Photomicrograph of a Straight Tungsten-carbide cobalt Hard Metal. (X 1,500 diameters). Note the Pools of Cobalt

Fig. 2. (*Right*) Polished and Etched Tungsten-carbide cobalt Hard Metal (X 2,500 diameters)



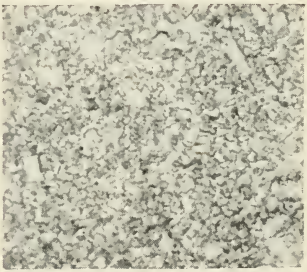
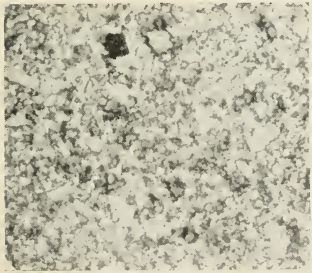


Fig. 3. (*Left*) Tungsten-carbide cobalt Mixture suitable for Cutting Tools

Fig. 4. (*Right*) A Tungsten-carbide cobalt Material of Fine Grain



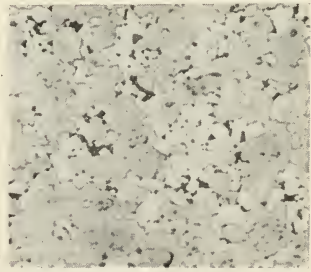


Fig. 5. (*Left*) Photomicrograph of a Hard Metal containing Tantalum Carbide

Fig. 6. (*Right*) Structure of Hard Carbide suitable for Machining Steel

Titanium-bearing grades are not so shock resistant as the corresponding cast-iron grades.

The hardness varies from 1,350 to 1,650 V.P.N. Hardness alone is not a sufficient criterion for cutting efficiency or abrasion resistance. For temperatures up to 500-600 deg. C. the hardness is retained reasonably well—a fact which undoubtedly explains the remarkable cutting properties of cemented carbides. The following table gives a selection of carbide properties.

SOME IMPORTANT PROPERTIES OF CEMENTED CARBIDES.

Property		Material	
		Straight Tungsten Carbide	Tungsten-Titanium Carbide
Density	gm./cm³	13·2—14·8	10·6—13·3
Compressive Strength	lb. per sq. in.	595,000—890,000	570,000—725,000
Compressive Strength (Proportional Limit)	,,	425,000—780,000	560,000
Torsion Strength	,,	430,000—200,000	100,000—130,000
Torsion Modulus	,,	18,500,000	
Transverse Breaking (Bending) Strength	,,	125,000—350,000	100,000—250,000
Fatigue Strength	,,	65,000—105,000	53,000—90,000
Impact Strength	Ft.-lb.	·7—1·75	·4—1·4
Hardness	V.P.N.	1,200—1,450	1,300—1,550
Young's Modulus	lb. per sq. in.	$80—97·5\times10^6$	$77·84\times10^6$
Coefficient of Thermal Expansion	$\times10^{-6}$/ deg. C.	4·8—5·8	5·0—6·3
Heat Conductivity	Cal./cm²/cm./ sec./deg. C.	0·18—0·21	·09—·15
Specific Heat	Cal./gm./	·05	·05—·06

Cemented carbide is of vital importance during times of war. All shells, for instance, are turned with carbide tools. Since tungsten is the main metal used in the cemented carbides, it can well be seen that supplies of tungsten are of paramount importance in time of peace and war alike. The Germans, who had no natural source of supply of tungsten ready to hand made very strenuous efforts to develop a grade of carbide which was completely free from tungsten. They were successful in developing a grade suitable for machining steel. This contained vanadium and titanium carbide bonded with nickel.

Besides being difficult to produce, this compound is not easy to braze on to steel shanks and to grind. Since its cutting efficiency is not up to the normal grades it is doubtful if it will continue to be produced unless lack of tungsten ore make it imperative.

A great deal of work has also been carried out on the production of a cutting tool, using a technique somewhat similar to that of the carbides, from sintered ceramic materials, such as aluminium oxide. Some success has been achieved, especially in the machining of light alloys and it may well be that the next major change in cutting materials will come from this direction.

CHAPTER 2

THE DESIGN OF CEMENTED-CARBIDE TOOLS

The cemented carbides described in the previous chapter can be applied to most chip-forming machining such as turning, boring, reaming, shaping, planing, milling, drilling, etc., as well as to many other uses such as wire-drawing and deep-drawing dies, cold heading and stamping. Use is also made of their extraordinary abrasion resistance on such components as lathe centres, centreless-grinder work rests and micrometer tips. Partly for reasons of economy and partly because of the comparatively low impact strength of carbides, they are almost invariably used in the form of tips or inserts secured to steel shanks or other members of suitable form. Since the cemented carbide is relatively expensive when compared with alternative materials such as high-speed steel, only the minimum amount necessary to give a satisfactory cutting edge and tool life is used. Provided that the tools are applied correctly, the many advantages which they offer are such as quickly to offset the increased initial cost.

The hard-metal manufacturers in Great Britain have standardised turning tools for most machining operations and catalogued tips and tools are designated by numbers which are used by all the manufacturers. The front and side clearance angles are kept constant so that it is necessary to state only the tool number, grade of tip and top rake, when ordering. As the majority of standard tools are cheaper and more readily available than similar tools of a special design, it is obviously desirable to adhere to standard catalogue designs as far as possible. Standard tips are shaped with the upper and lower surfaces parallel and with relief angles on the side and front. The correct top rake on the tool is obtained by milling the base of the seating in the shank at the required angle.

Before deciding on the type of tool for any particular machining operation, it is necessary to have precise information of the component, material to be machined, type of machine, condition of machine, etc.

In spite of the considerable development which has taken place in such operations as milling, single-point turning tools still account for the largest proportion of carbide applications. As every basic principle in the design of carbide tools is used on single-point tools, it is well worth while to spend some little time in examining their design in detail, before proceeding to the more complicated cutting tools.

As the account of the mechanical properties of the cemented carbides on page 12 shows, they are very strong in compression, but relatively weak in impact or shear. Thus a tool must be designed

with a view to stressing the tip in compression only, and to give it the greatest possible support by means of a suitably shaped seating in the shank, and by the minimum possible clearance. This point cannot be emphasised too strongly ; even to-day there are many machine shops who misuse and waste carbide tools by trying to use them with the same rakes and clearances as high-speed steel tools.

If we consider the force acting on a lathe tool used for bar turning, it may be resolved into three component forces acting in the directions shown in Fig. 1. The force due to the feed F is against the side of the tool in a direction parallel to the axis of the work. The force R represents the radial pressure which acts against the nose of the tool in a direction at right angles to the axis. The third force T represents the tangential pressure which is directed vertically downwards on top of the tool. The resulting force represented by the diagonal E must

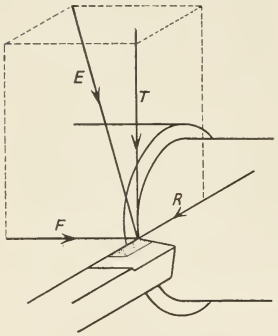


Fig. 1. Diagram illustrating the Forces acting on a Turning Tool, and the Direction of the Resultant Force

be considered when deciding the type of seating, depth and shape of shank, thickness of tip, and other points in design.

The most elementary form of carbide tool is shown in Fig. 2 in which the tip is brazed on the top of a steel shank. It is a useful expedient where a tool is wanted quickly for a light cut, especially on cast iron.

The front support may be improved by milling a recess across the front of the shank as shown in Fig. 3. This type of seating is used on straight round-nosed turning tools (600-650 series) ; turning and facing tools (950-1000 and 1050-1100 series) ; and parting and grooving tools. The resultant force may be directed towards the back of the recess by cranking the end of the shank as shown in Fig. 4. This type of seating is used extensively on tools for machining cast iron.

Another method which is suitable for shallow cuts on cast iron and non-ferrous metals is to seat the tip on a side-milled recess, Fig. 5.

The tip is adequately supported against side thrust, but since there is no support from the shank at the side of the tip, the radial pressure R (Fig. 1) must be resisted by brazing alone.

The type of seating most generally used on turning tools, especially for machining steel, is produced by end-milling the recess in the side of the shank as shown in Fig. 6. Good support by the shank is given on three sides of the tip.

FIG. 2

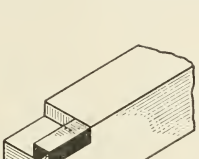


FIG. 3

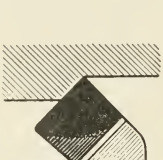


FIG. 4

FIG. 5

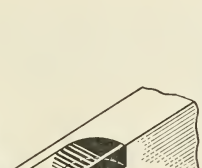


FIG. 6

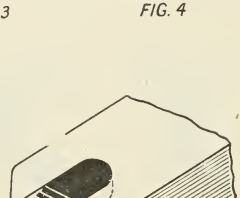


FIG. 7

Fig. 2. A Simple Carbide Tool for Light Cuts, used generally as an Expedient

Fig. 3. A Simple Carbide Tool seated in a Milled Recess

Fig. 4. Cranking the Tool as shown directs the Resultant Force into the Back of the Milled Recess

Fig. 5. Method of Carbide-tip Mounting which is suitable for Shallow Cuts on Cast Iron

Fig. 6. Type of Seating generally used

Fig. 7. The Maximum Protection to the Tip is given by this Form of Seating

There is one other form of seating, illustrated in Fig. 7, which gives the maximum possible protection to the tip. This seating can be used with advantage on planing tools. Precautions must be taken to avoid brazing strains—a point which will be dealt with more fully in Chapter 3.

Types of Tool

The type of tool for any particular job will depend on the operation and the machine. The standard basic tool types can be used for a wide variety of operations. For instance, a 700-series tool as shown in Fig. 8 can be used for turning up to a shoulder, *A* ; or for facing *B* ; or by setting the tip at angle, the tool is suitable for a straight turning cut *C* or for chamfering *D*.

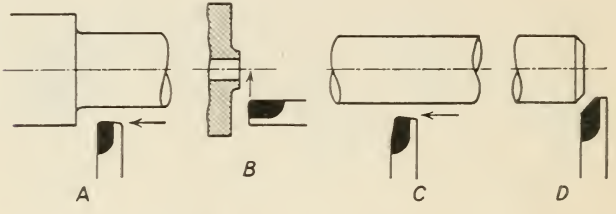


Fig. 8. (above) Illustrating the Application of a Standard Basic Tool Tip to Various Turning Operations; A—Turning to a Shoulder; B—Facing; C—Bar Turning; D—Chamfering

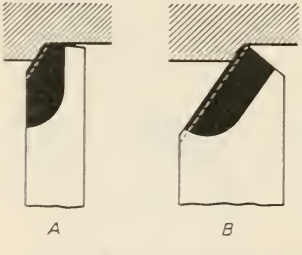


Fig. 9. (left) Economical and Uneconomical Types of Tip with regard to Regrinding

When deciding the shape and position of the tip, due consideration should be given to regrinding. For instance, tool *A* in Fig. 9 will be found more economical than tool *B* on jobs such as bar turning.

Shank Material and Size

The usual shank material is a 0·5 per cent carbon steel in the normalised or annealed condition. A good general indication of the relative dimensions of tip and shank are given in the hard-metal manufacturers' catalogues of standard tools. One safe rule is to make the depth of the shank four times the tip thickness.

Alfred Herbert Ltd., the manufacturers of Ardoloy tools, have constructed a useful alignment chart, reproduced in Fig. 10 for determining the most suitable shank section of tool. The required depth of cut and the feed in inches per revolution are joined by a straight edge; the point of intersection *X* on the construction line is joined by a straight line to the amount of tool overhang on the right. The

shank section is indicated by the intersection of this line with the shank-size scale. The example shown by the dotted lines assumes a depth of cut of $\frac{1}{8}$-inch, a feed of 0·015-inch per revolution and a tool overhang of $1\frac{1}{2}$ ins. The shank is therefore $\frac{3}{4}$-inch square, $\frac{1}{2}$-inch by 1 inch, or $\frac{5}{8}$-inch by 1 inch.

The base of the shank should be milled or ground flat so that it will sit firmly in the tool box without rocking.

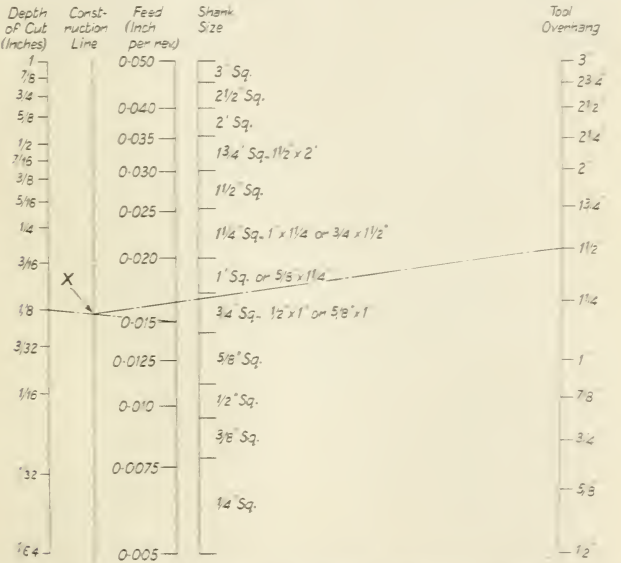


Fig. 10. Chart for Determining the Most Suitable Shank Section for supporting the Tip

GRADE OF CARBIDE.—The type of tool having been decided upon it is then necessary that the correct grade and size of tip be chosen. It was shown in Chapter 1 that there is a considerable difference between the carbide used in machining steel and that used for cast iron and most other materials. Grades of carbide developed by certain well-known manufacturers for machining various types of materials will be found listed in Chapter 6. It will be found that the two general-purpose carbides for cast iron and steel will cover most machining jobs. No satisfactory universal grade has yet been produced. It is well to remember that nickel and high-nickel alloys such as Monel metal give a chip with a marked cratering tendency and should be machined with a grade recommended for steel cutting.

Tool Angles

As Dr. D. F. Galloway has pointed out in his booklet "Cutting Tool Nomenclature," published by the Research Department of the Institution of Production Engineers, there is a considerable degree of confusion in the naming of tool angles.

The system of nomenclature shown in Fig. 11 has been agreed to by most of the trade associations concerned and will probably form the basis of a British Standard specification for single-point turning tools. The proposed terms to be used, as indicated in Fig. 11 are as follows :—

A	Side Top Rake Angle.
B	Front Top Rake Angle.
C	Composite Rake Angle.
D	Side Clearance Angle.
E	Secondary Side Clearance Angle.
F	Front Clearance Angle.
G	Secondary Front Clearance Angle.
H	Side Wedge Angle.
J	Front Wedge Angle.
K	Plan Approach Angle.
L	Plan Trail Angle.
M	Included Plan Angle.
N	Nose Radius.
O	Composite Rake Plan Angle.
P	Side Cutting Edge.
Q	Front Cutting Edge.
R	Face.
S	Flank.
T	Heel.
U	Nose.
V	Shank.
W	Base.

The plan approach angle is best set at 10 deg., unless it is necessary to machine square to a shoulder, when it must be reduced to 0 deg. An approach angle of 10 deg. ensures that the initial load, on starting the cut, is taken a little way back from the nose of the tool where the tip is stronger. Another advantage is that, on finishing the cut, the chip load is gradually reduced as the tool leaves the workpiece.

In work which is long in relation to its diameter, it may be advisable to reduce the side cutting edge angle since increase of this angle causes a corresponding increase in the force *F* shown in Fig. 1.

The nose radius when turning steel should be kept as small as possible ; a large nose radius may produce a chip like a thin curved wedge as shown in Fig. 12 at *A* instead of a parallel chip thinning at one edge as shown at *B*. For general work a $\frac{1}{32}$-inch radius will be found satisfactory. A thin chip produces excessive chip pressure immediately behind the cutting edge, causing cratering which leads to chattering.

bad surface finish and rapid collapse of the cutting edge. It is advisable to increase the nose radius when taking an interrupted cut. Many prefer to use a chamfer instead of a radius.

To ensure strength at the nose of the tool the included plan angle should be kept as large as possible. The corresponding plan trail angle will then be just large enough to clear the workpiece without causing the nose to rub. This angle should not be less than 8 deg. C. and for tools taking a plunge cut it may be increased to as much as 30 deg.

Clearance and Relief Angles. The side and front clearance angles should be just sufficient to avoid the work. Since the cemented

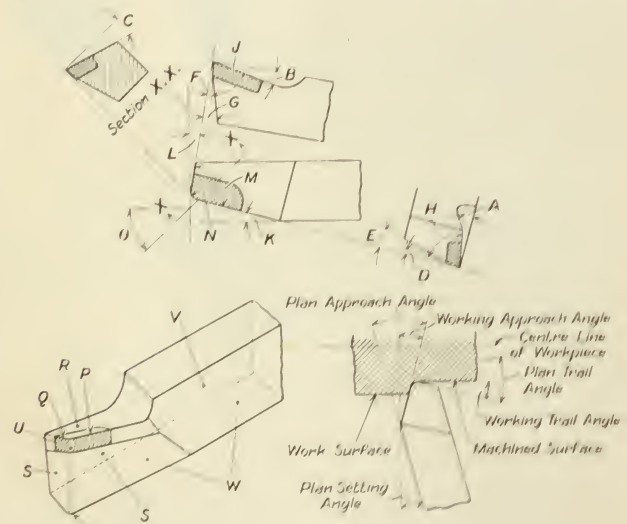


Fig. 11. Tool-angle Nomenclature

carbide has a low shear strength, too great a clearance angle weakens the cutting edge, especially if the tip is thin. The clearance angle for the shank should be made 2 deg. greater than the clearance angle for the tip, Fig. 13, to avoid grinding the steel shank with the soft green grit wheels used for the tip. If the cutting edge is to be diamond lapped, a secondary relief angle, Fig. 14, will shorten the lapping time. Clearance angles of up to 6 deg. are adequate for most jobs. For plastics, rubber and other non-metallic materials, this may be increased to 10 deg.

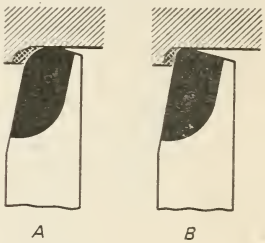
Top Rake.—The top rake is the most important angle on the cutting tool. It is essential to see that this angle is maintained by holding the tool on centre, when setting up in the lathe, and that the correct angle be maintained during regrinding.

Materials such as cast iron or bronze which give a brittle crumbly chip require a small top rake of from 0 deg. to 6 deg.—the harder the metal the smaller the top rake. Copper, aluminium, and aluminium alloys produce a continuous chip tending to bind on the top face of

Fig. 12 (right). Showing the Influence of Nose Radius on Chip Form

Fig. 13. Use of Clearance Angle to avoid Grinding the Shank when the Tip is Reground

Fig. 14. Use of Secondary Relief when the Tool is Diamond-lapped



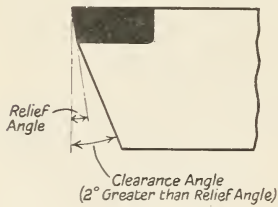


FIG. 13

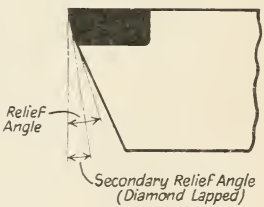


FIG. 14

the tip. A top rake of from 12 to 14 deg. with these metals ensures that the tool is free cutting. Aluminium and aluminium alloys are particularly troublesome because of their tendency to form a built-up edge on the tip. Special grades of carbide are available which help to get over this difficulty.

Steel, when being turned, normally produces a springy continuous chip which has a tendency to bind or weld on to the top face of the tip. The rapid movement of the chip across the face of the tip results in a characteristic erosion behind the cutting edge known as "cratering." Straight tungsten-carbide cobalt mixtures show this welding tendency to such a degree that it is not possible to use them for machining steel, except for steel castings where greater resistance to abrasion from sand and scale offsets their bad cratering properties. Additions such as titanium carbide to the tungsten-carbide cobalt mixture help to overcome the cratering trouble, but at the same time weaken the tip

and make it more difficult to grind. Increasing the top rake on the tool reduces the chip pressure but also lowers the shear strength of the cutting edge. The chip pressure is too great when machining steel to allow a large top rake to be used, so that in practice a compromise has to be effected. One method of increasing the strength of the cutting edge whilst avoiding excessive chip pressure is to grind a negative land equal in depth to the feed along the cutting edge as shown in Fig. 15. Generally speaking, the higher tensile steels require a lower top rake.

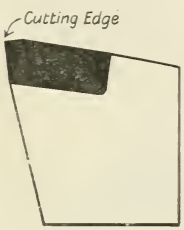


FIG. 15

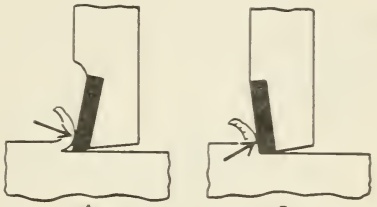


FIG. 16

Fig. 15. A Negative Land with a Width equal to the Depth of Feed increases the Strength of Cutting Edge and avoids Excessive Chip Pressure

Fig. 16. Showing the Main Function of Negative Rake: A—Positive Rake; B—Negative Rake. Note the Direction of the Thrust away from the Weak Tip and into the Body of the Tool

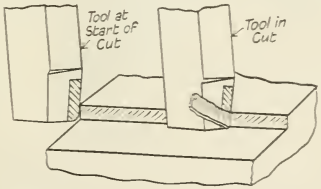


Fig. 17. Action of a Planing Tool having a Negative Front Top Rake and a Positive Side Top Rake. Note that the Direction of Chip Flow follows the True Top Rake

The use of negative top-rake on carbide tools has received a considerable amount of attention during recent years. It undoubtedly has a number of advantages. Briefly, the function of negative rake is to direct the chip thrust away from the cutting edge where the tip is weak, into the body of the tool, Fig. 16. Also the fact that the cutting edge is strengthened allows the use of a harder grade of tip.

It should be observed however that the chip flow takes place in the direction of true rake, which is given by the composite rake angle *C*,

and the composite plan angle θ as shown in Fig. 11. The actual direction of chip flow in the case of a planing tool having a negative front top rake angle and a positive side top rake angle is indicated in Fig. 17.

Some power consumed by negative-rake turning is largely absorbed as heat in the chip. This heating causes a softening of the chip which has the effect of lowering the chip pressure. It is most important to note that alloy steels which retain their strength at raised temperatures are not amenable to negative rake machining. Negative-rake carbide tools find a particular use in the milling of steel, on planing and shaper tools, and for facing cuts. (For detailed information on the use of negative-rake and the relation between speeds and cutting force, the reader is referred to Machinery's Yellow Back No. 20, "Negative-Rake Milling.")

Chip Breakers

There is one more point remaining to be dealt with in connection with top rake. With the machining of steel, a long hot flexible turning is produced which is dangerous to the operator and difficult to handle and dispose of. An effective method of controlling the chip is by the use of a groove ground along the cutting edge. This groove causes the chip to come off as a continuous spiral, or as short chips which are broken against the uncut portion of the workpiece. The chip-breaker groove should be sufficiently deep to break up the chip but not so deep as to cause the chip to jam up the groove and thus fracture the tip. A depth of 0·015 to 0·020-inch is generally suitable. The width of the groove affects the chip shape, the narrower the groove the shorter the chip. Recommended widths of grooves are shown below in the table.

RECOMMENDED WIDTHS OF CHIP BREAKERS.

Depth of Cut (inches)	Feed—Ins. per Rev.				
	008–012	013–017	017–022	023–027	028–032
	Width of Chip Breakers (ins.)				
1/64–3/64	1/16	5/64	3/32	7/64	1/8
1/16–1/4	3/32	1/8	5/32	11/64	3/16
5/16–1/2	1/8	5/32	3/16	13/64	7/32
9/16–3/4	5/32	3/16	7/32	15/64	1/4

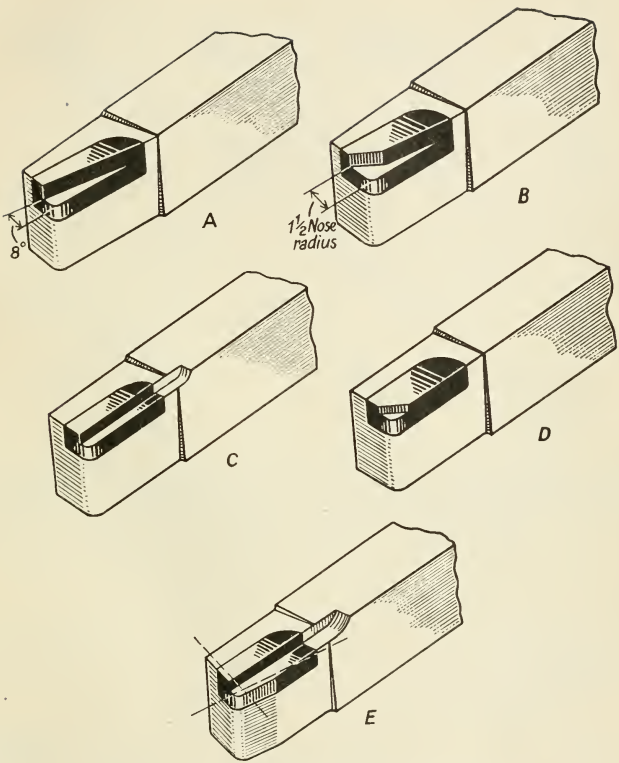


Fig. 18. Types of Grooving for Chip Breaking

The most generally used form of chip breaker is shown at *A* in Fig. 18. Where this form of tool has a large nose radius it is advisable to grind a second groove as shown at *B*. A parallel groove as shown at *C* is best when taking a varying depth of cut or when machining to a shoulder ; and a 45 deg. groove *D* on finishing cuts.

One disadvantage of the usual chip breaker is that it is not easy to recondition the tool by off-hand grinding. The form of chip breaker shown at *E* overcomes this objection. When this tool becomes worn it is merely necessary to grind back the front and side faces of the tip, leaving the chip groove untouched. Thus the new faces would be parallel to the old faces as shown by the dotted lines.

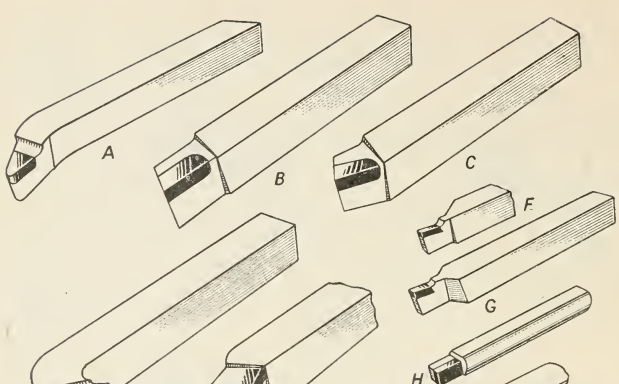


Fig. 19. Representative Collection of Standard Tools: A—Cranked Round-nosed Turning Tools B—Bar-turning Tool for Machining to a Shoulder; C—General-purpose Bar-turning Tool; D and E—Turning and Facing Tools; F—Offset Parting Tool; G—Central Parting Tool; H—Round-shanked Boring Tool; J—Large Round-shanked Boring Tool

It is sometimes an advantage on roughing cuts to lap the groove to a 2 to 3 deg. negative top rake at the cutting edge.

The principles of the design of single-point turning tools has been examined in some detail. In the remainder of this chapter examples of the actual tools used in industry illustrate the points which have just been discussed.

Some typical standard lathe tools are shown in Fig. 19. The numbers in brackets in the following description refer to the standard tool catalogue number used by most of the British manufacturers. Fig. 19 *A* shows a cranked round-nosed turning tool (600 series) suitable for light general-purpose work, especially on cast iron and non-ferrous metals and plastics. For steel turning, tools *B* and *C* are most used (700 and 750 series) as this type of seating offers the maximum support for the tip. Turning and facing tools (950 and 1000 series) such as that at *D* are particularly useful for cast iron machining. Parting tools (1150 series) are shown at *F* and *G*. The undercut back to the seating shown in the offset parting tools *F* and *G* is a better support for the tip than the normal seating. Boring tools are shown at *H* (1475 series) and *J* (1500 series). The end-milled type of seating used in *J* is preferable for tools above $\frac{5}{8}$-inch diameter as this gives better support for the tip than the seating used for *H*. Small boring tools up to $\frac{1}{4}$-inch diameter are best made in solid carbide. On the example shown in Fig. 20, which is used for machining the bore of small leaded-bronze

bushes, a secondary clearance angle of 14 deg. is provided to enable a mirror finish to be diamond lapped on the cutting edge.

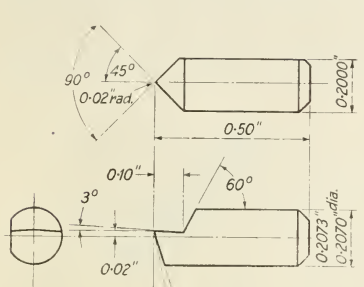


Fig. 20. Solid Carbide Boring Tool with a Secondary Clearance to facilitate Diamond Lapping

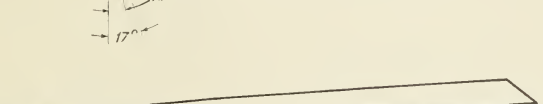


Fig. 21. Turning Tool for Copper Commutators

Fig. 22. Planing Tools

Turning tools for copper commutators, Fig. 21, usually have a top rake of 30 deg. Typical planing tools are shown in Fig. 22. Tools of this kind are used mainly for cast iron. In this instance, negative top rake may be advisable to strengthen the cutting edge.

Carbide-tipped tools are now also available for Swiss-type automatics, where the advantages of a tool that requires a minimum of regrinding and is capable of cutting at high speeds are obvious.

Shaving Tools.—Hard-metal tipped shaving tools are very

suitable for machining copper and aluminium alloys. The front clearance angle should be kept as large as possible, preferably more than 35 deg. in order to keep the tool free-cutting. A good example of a shaving tool is the form tool shown in Fig. 23, used for cutting the copper driving-band of the 4·5 shell. The tool is set in a special tool holder at an angle of 8 deg. The tool is fed under the component, the cut being taken gradually on the cutting edge which is set at 45 deg.

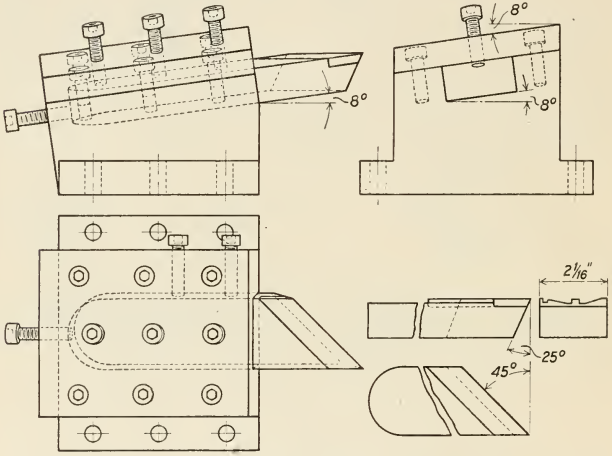


Fig. 23. Shaving Tool in Special Tool Holder

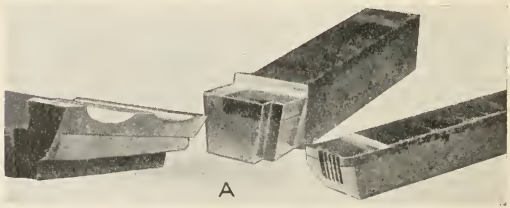


Fig. 24. Form Tools for Machining Plastics

Regrinding is a relatively simple operation of surface grinding the front of the tool. Greatly improved tool life can be obtained by diamond lapping the cutting edge.

Form Tools.—Fig. 24 shows a number of tipped form tools for

machining plastics. For form tools where the cutting edge is greater than 1 inch in length a composite construction, as shown in Fig. 25, helps to eliminate brazing stresses.

In designing form tools, sharp corners should be avoided as far as possible. Such corners cause stress concentrations leading to cracks during grinding and whilst the tool is in use. The grades of carbide

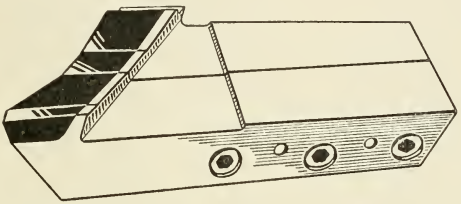


Fig. 25. Wide Form Tool of Composite Construction

used for steel especially finishing, are difficult to grind, without cracking, in complicated shapes.

Effect of Tool Design on Power Consumption

Research by A. C. Wickman Ltd., Coventry, into the effects of tool design on power consumption has been carried out over a number of years and the results of investigation into the type of chip produced by various tool shapes, compared with the power consumed in producing them, together with considerations of design for maximum resistance to breakage under conditions of heavy cutting pressure, has enabled tungsten-carbide tipped tools to be designed with improved mechanical efficiency.

Many users of tungsten-carbide tools have followed high-speed steel tool practice in employing round nose tools. This type of tool produces a chip which is not uniform in cross section. Such a chip requires considerable horse-power in cutting, not only because of its form, but, more especially, because of the bending required by the curved section in guiding it along the top rake of the tool. This is not so important in the case of grainless materials, such as cast irons and brass alloys, as it is in the case of steels having a definite grain, or in materials, *e.g.* nickel irons and chilled iron, which produce a high cutting pressure. The production of a flat chip reduces very considerably the horse-power absorbed in curling the chip after partition from the parent metal. An increase in the angle of approach lengthens the chip produced for an equivalent depth of cut, also producing a thinner chip for an equivalent feed rate.

This point is demonstrated in Fig. 26, where the form of chip

produced by a round-nose tool is indicated at A and may be compared with B, a normal type of turning tool with a small approach angle. In this type of tool, as in the standard type of bar turning tool, the chip thickness is almost the same as the feed. Where the work-piece is such that lengthening of the cutting edge can be employed without inducing chatter, the total pressure on the cutting edge on engagement is approximately the same as in cases A and B, but the unit pressure

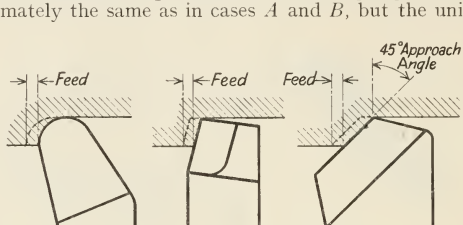


Fig. 26. Illustrating the Influence of Nose Radius on Chip Thickness, and of the Chip shape on the Power Absorbed. A—Round Chip and Long Cutting Edge; B—Flat Chip and Short Cutting Edge; C—Flat Thin Chip and Long Cutting Edge

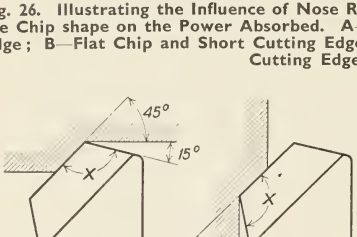


FIG.27

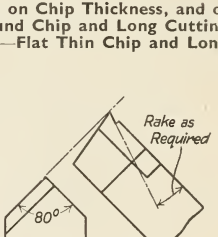


FIG.28

Fig. 27. Heavy-duty Turning and Facing Tool

Fig. 28. Light Turning Tool on which a Chip Breaker may be Ground, but limiting Tool to either Right- or Left-hand Use

is very much less, resulting in longer life of the cutting edge before the tool requires regrinding. The form of tool shown at C has been developed for use on heavy turning, as encountered in boring and turning mill practice, heavy centre lathe practice, for continuous or interrupted cuts.

Fig. 27 illustrates the application of the tool to both turning and

facing operations. The reduction of the back clearance angle to 15 deg., as compared with 45 deg. in current practice, produces a considerably stiffer angle at X, thus reducing the liability of breakage of the point at these positions, particularly when interruptions in the cut are encountered. The makers recommend that this type of tool be applied only in square section shanks, in order to resist the twisting effect of cutting pressure when the tool is fully loaded, thus eliminating as far as possible the abrasive effect of vibratory movement which would arise in the case of a shank of rectangular section. Consequently, these tools are available in shank sizes from $\frac{3}{4}$-inch square up to $1\frac{1}{2}$-inches square, in $\frac{1}{4}$-inch increments, but larger sizes can be made.

In the case of light turning tools, where cutting pressures are relatively low, there is no necessity to stiffen the tool to the extent just described, and the tool shown in Fig. 28 therefore is designed to use for either right-hand or left-hand traversing, with or without a chip breaker on the appropriate cutting edge. It has a 50-deg. approach angle and a 50-deg. back clearance angle. This type of tool is designed particularly for those cases where the tool must be fed into the work before a traverse in either direction can be made, and is recommended to take the place of round-nose tools in order to conserve horse-power in chip production, leaving the maximum horse-power input for chip removal and the maximum exploitation of the machine tool. Again, the makers recommend square shanks for the whole range of these tools, from $\frac{3}{8}$-inch square, up to 1-inch square.

Cylindrical Cutters

Carbide-tipped milling cutters have been successfully used for the face-milling of cast iron for many years. More recently carbide

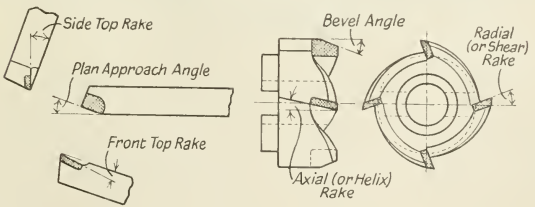


Fig. 29. Angles on a Cylindrical Cutter and their Corresponding Angles on a Single-point Cutter

has been used to an increasing extent for milling of light alloys, especially aircraft spars, and also for steels. As milling machines especially designed for steel milling become available, the use of carbide will doubtless become even more extended.

As a tipped milling cutter can be regarded as a collection of single-point tools, the principles that apply to the design of single-point

tools for interrupted cutting can be used equally well for milling cutters. The illustration Fig. 29 shows the similarity between single-point turning tool angles and the corresponding angles on a milling-cutter blade. The side top rake angle becomes the axial (or helix)

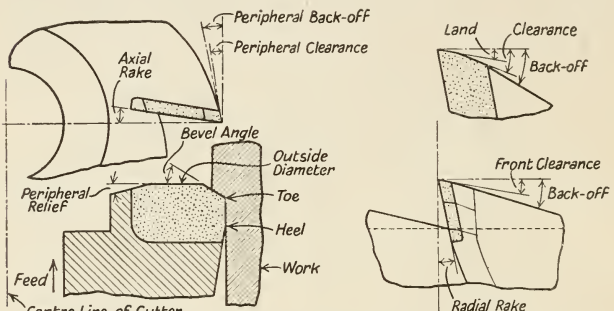


Fig. 30. Angles on a Cylindrical Cutter

angle on the milling cutter ; the front top rake angle becomes the radial (or shear) angle ; and the plan approach angle is the bevel angle on the milling cutter. The various angles on the tip of a cylindrical cutter are shown in greater detail in Fig. 30.

Angles and Clearances on Tipped Cylindrical Cutting Tools

Radial Rake.—Spot facers, core drills and reamers do not usually require any radial rake. A safe general rule for milling cutters for brass, bronze and cast iron is to start with a 5-deg. positive and then vary from this until the cutter is free-cutting without chipping of the cutting edge. For dead-soft steels an increase in the radial rake to 8 deg. ; for copper 10 deg., and for some aluminium alloys as much as 12 deg., may be found necessary to ensure free cutting. High tensile steels need negative radial rake down to 8 deg. : the harder the steel the greater the negative rake. On such operations as face milling to a shoulder, and slotting, where it is not possible to bring the start of the cut away from the toe of the cutter blade because of the small bevel width, it is necessary to use negative radial rake. As with single-point turning, negative radial rake may cause increased power consumption and should be avoided when possible.

Axial or Helix Rake.—Reamers and spot-facing cutters do not require axial rake. On milling cutters, axial rake angles up to 5 deg. positive are common for cast iron, brass and bronze.

For steel, axial rake angles vary from 3 deg. positive to 15 deg. negative depending on the hardness of the steel. The axial negative rake should be sufficient to ensure that the impact on starting the cut is taken away from the toe of the blade. Negative axial rake increases the thrust along the axis of the cutter and may make the maintenance of size on the workpiece difficult.

If a cutter is producing a satisfactory surface finish without chipping the cutting edge of the cemented carbide, there is no advantage in using negative axial or radial rake. Apart however, from increasing the strength of the cutting edge, negative rake on milling cutters produces an excellent surface finish.

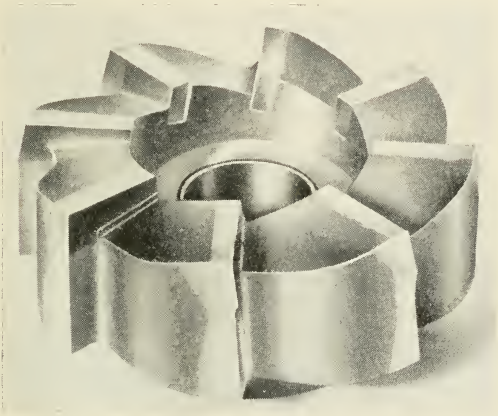


Fig. 31. Solid Cutter—Herbert Carbiface

Bevel Angle.—The bevel angle is equivalent to the approach angle on single-point turning tools. Its function is primarily to take the initial impact of the cut before the point or toe of the blade. The remarks earlier in this chapter which deal with the use of the approach angle and nose radius or chamfer on turning tools apply equally well to the milling or other types of circular cutters. It is, however, more difficult to generate a radius on the blade of milling cutters than on turning tools, and for this reason a simple chamfer or secondary angle is more usual to break the corner or the heel of a milling-cutter blade. Again, as with the approach angle on turning tools, the length of the bevel or the cutting edge must be longer than the greatest depth of cut. $\frac{1}{32}$-inch is sufficient on reamers and finishing cuts, and twice this amount should be allowed on roughing.

For reamers, core drills and counterbores, a bevel angle of 45 deg.

is satisfactory for most metals. On milling cutters for finishing, a radius is often preferable to a chamfer. For general-purpose milling, a 45-deg. bevel angle will be found satisfactory. For steel this should be reduced to 15 or 20 deg. If there is a tendency for the toe of the blade to chip, increasing the chamfer should be tried. If this fails the bevel angle can be reduced.

Clearance and Back-Off Angles.—On milling cutters the clearance angles on the periphery should be from 4 to 6 deg. with the steel body backed off by an additional 3 to 5 deg.; the softer the metal the greater the clearance.

End-cutting tools such as spot-facing cutters and shell drills require a clearance angle on the cutting edge of 4–7 deg. for steel, cast iron, brass and bronze, and 8–10 deg. for the softer materials such as aluminium, copper and plastics. The steel back-off angle is made correspondingly greater. The smaller diameter cutters often require a greater amount of backing-off to give the required swarf clearance. This is not so serious as might be imagined because the duty is not generally so severe as to cause breakdown of the cutting edges due to overloading.

Examples of Circular and Cylindrical Cutters

The main application of cemented carbide has been face milling, although carbide can equally successfully be applied to side-and-face cutters, straddle milling and end milling. Spiral-fluted cutters are not practicable, partly because of the difficulty of mounting and grinding

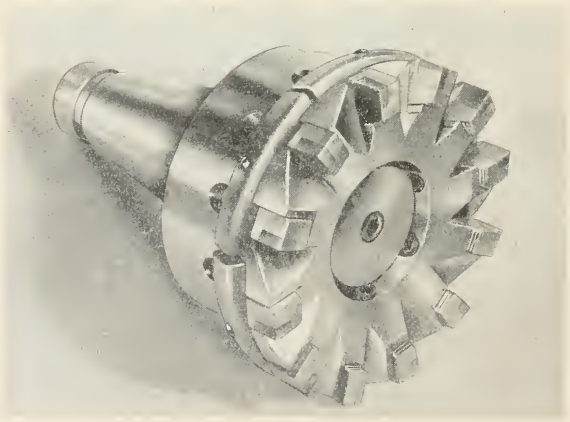


Fig. 32. Inserted-blade Carbide-tipped Face-milling Cutter

the tips, and partly because of the difficulty of getting sufficient feed per tooth.

Cutters below 6 inches in diameter are usually made by brazing carbide tips into a forged steel or high tensile cast iron body. A Herbert Carbiface cutter using negative axial rake designed for the milling of steel as shown in Fig. 31 is a typical example of a solid cutter. This simple rugged and inexpensive design is ideally suited for small cutters and for jobbing work. The main disadvantage lies in the difficulty of reconditioning the cutter should one of the tips be smashed or badly chipped.

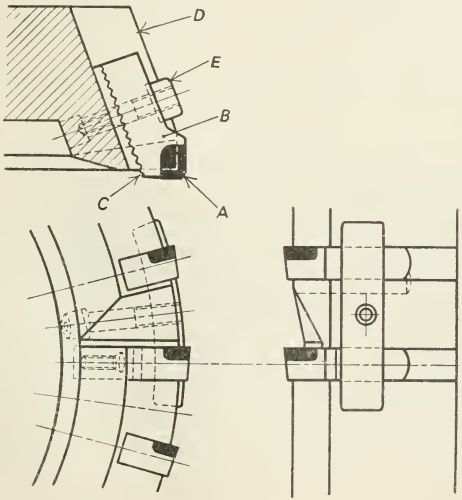


Fig. 33. Construction of the Herbert Cutter shown in Fig. 32

The inserted-blade type of cutter is to be generally preferred for diameters larger than 6–8 inches. One advantage of the inserted blade cutter is that it is possible to replace one broken blade without disturbing the rest of the cutter. If the cutter has an even number of teeth it is possible to set half of them back so that only the other half are cutting, thus enabling the cutter to be used on a machine which would otherwise lack the power required for carbide milling. Where a large amount of production milling is required, these advantages offset the complication and expense of providing suitable locking arrangements for the tips on the cutter body.

A number of locking devices are in common use. The illustration, Fig. 32, is of a Herbert face milling cutter. The way in which the

blades are secured to the cutter body is shown in Fig. 33. Each blade *B* is tipped by a carbide tip *A* and has transverse serrations at *C* which engage similar serrations in the cutter body *D*. The serrations afford an adjustment to the blades which are secured by the clamp *E* and socket-head screws.

Fig. 34. Method of Securing Blades in the " Production " Head

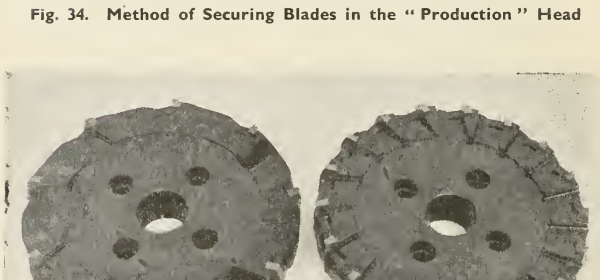


Fig. 35. Two Examples of Wimit Multimill

Another method of securing the carbide-tipped blades which are of a somewhat simpler design is shown in Fig. 35. An application of this type, the Production cutter, is to the milling of motor-car cylinder blocks.

Another type of inserted-blade milling cutter is the Wimet Multimill. Two examples of this are shown in Fig. 35. This cutter is made with a 10-deg. positive radial rake, and a 10-deg. negative helix rake. Modification to the radial rake is obtained by the addition of a primary rake of approximately 0·015-inch wide along the cutting edge. The table on p. 35 gives values of speed, rakes, metal-removal rates, and other data for this cutter, The true rakes given in the table are obtained from the standard radial and helix rakes, and a standard bevel of 15-deg.

RECOMMENDATIONS FOR WIMET MULTIMILL APPLICATIONS

Material	Machining Speed F.P.M. Roughing	Machining Speed F.P.M. Finishing	Radial Rake	True Rake	Prim'y Rake	Wimet Grade	Met. Rem. Rate, Cu. in./HP/Min.
			deg.	deg.	deg.		
15 per cent. C. Forgings and Bar ..	750	1,000	10	7	—	X 8	0·93
3–0·4 per cent. C. Forgings and Bar ..	680	850	10	7	—	X 8	0·85
3–0·4 per cent. Castings	350	420	0	–2	–9	X 8	0·7
7 per cent. C. Forgings and Bar ..	250	400	3	0	–7	X 8	0 72
per cent. Nickel ..	350	420	6	3	–4	X 8	0·6
per cent. Chrome—55 tons Forgings and Bar	450	550	6	3	–4	X 8	0·7
ckel-Crome, 65/75 tons—Forging and Bar	450	550	3	0	–7	X 8	0·65
ckel-Chrome, 100 tons Forging and Bar ..	225	250	0	–2	–9	X 8	0·6
per cent. Chrome-Manganese (Normalised)	400	500	3	0	–7	X 8	0·7
ainless Steel—Forgings and Bar ..	90	120	18	15	8 Lip	H	0·5
stings	Up to 100		6	3	4	X 8	0·4
st Iron (200 Brinell) ..	180–250	350–400	10	7	—	H	1·25
ntrifugal Iron Castings	135–200	200–300	6	3	–4	H	1 25
ckel Iron (I per cent. Nickel	150–200	200–300	6	3	–4	H	1·25
ckel Iron (10 per cent. Nickel)	25–35	25–45	0	–2	–9	H	1·00
lleable Iron (low steel content)	180–250	350–400	10	7	—	H	1·25
lleable Iron (high steel content)	300–500	400–500	3	0	–7	X 8 or H	0·9
pper	Up to 3,000		18	15	8 Lip	H	3·0
pro-Nickel	350–500	400–600	10	7	—	H	2·0
t Brass	Up to 1,000		6	3	–4	H	1·5
st Brass	400–600	500–1000	6	3	–4	H	1·2
osphor Bronze ..	400–600	500–1000	6	3	–4	H	1·15
uminium Bronze ..	400–600	500–1000	6	3	–4	H	1·13
nganese Bronze ..	400–600	500–1000	6	3	–4	H	1·01
uminium Alloys ..	Unlimited		10	7	—	X 8	6

When the 15-deg. bevel is altered, the true rake is accordingly changed and the primary land on the blade should be altered in accordance with the values :—

True Rake	Primary Land on Blade	
	For Sq. Corners and No Bevel Angle.	For 45° Bevel Angle.
−2 deg. ..	−12 deg. ..	− 2 deg.
0 ,, ..	−10 ,, ..	− ,,
3 ,, ..	− 7 ,, ..	+3 deg. Lip.
7 ,, ..	− 3 ,, ..	+7 ,, ,,
15 ,, ..	−5 deg. Lip ..	+15 ,, ,,

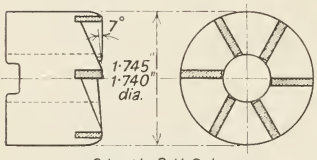


Fig. 36. Spot-facing Cutter for Cast Iron

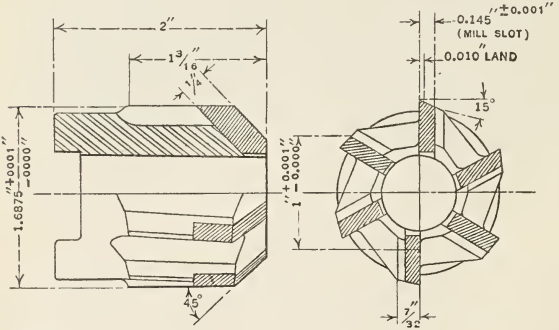


Fig. 37. Shell Drill for Enlarging a Hole in an Iron Casting

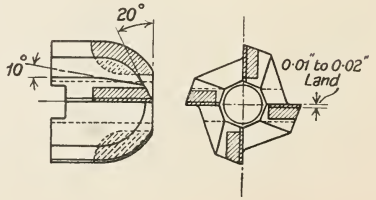


Fig. 38. Circular Form Cutter for Cast Iron

The method of locking a serrated blade in a serrated taper shown in the piloted boring cutter illustrated in Fig. 39 may be applied equally well to milling cutters.

The principle of reducing the number of teeth in a cutter to fall in line with the power limitations of the machine tool is taken to the limit in fly-cutting, in which a single cutter is used. The blade is clamped in a simplified cutter body at the same angles suitable for a multi-blade cutter. For depths of cut greater than $\frac{1}{16}$-inch it is an advantage to use two blades, one of them being set slightly lower than the other to give a finishing cut. Using a simple design of blade it is an easy matter to re-sharpen by off-hand grinding and then reset the

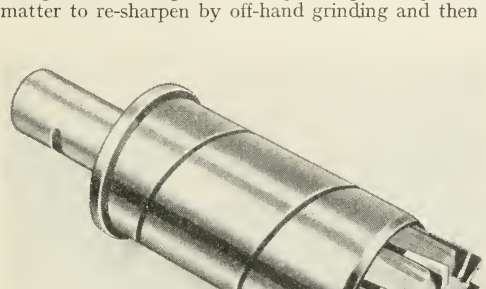


Fig. 39. Boring Cutter with Piloted Body (Richard Lloyd Ltd.)

blades in the body by means of a gauge. A single-tooth fly cutter is an excellent tool for taking a finishing cut over a rough-milled surface on light alloys where extreme accuracy and flatness are required.

Fig. 36 shows a spot-facing cutter for machining cast-iron cylinder blocks. Standard tips are used which fit into slots milled at an angle to the cutter body. The carbide tip is backed off by 7 deg. on the top of the cutter and the body is relieved by 30 deg.

A shell drill for enlarging a hole in an iron casting is shown in Fig. 37. As with the spot facing cutter in Fig. 36 a standard tip is used. The tip is seated in a slot with the base at 45 deg. to the axis of the body. A positive helix angle is formed by milling the slot at the required angle to the axis. The periphery of the cutter is backed off by 15 deg. and the bevel angle by 8 deg. A 0·010-inch circular land is shown on the outside diameter of the tips. Provided that the drill does not bind, a larger land of up to 0·025 inches would give longer life. On very bad castings trouble is sometimes caused by the carbide

tips chipping when using the simple 45-deg. bevel angle shown. A secondary angle of 15 deg. ground along the end of the cutter tips, leaving $\frac{1}{32}$-inch at 45 deg. at the periphery will help to overcome this difficulty. Another type of seating is shown in the circular form cutter for cast iron in Fig 38.

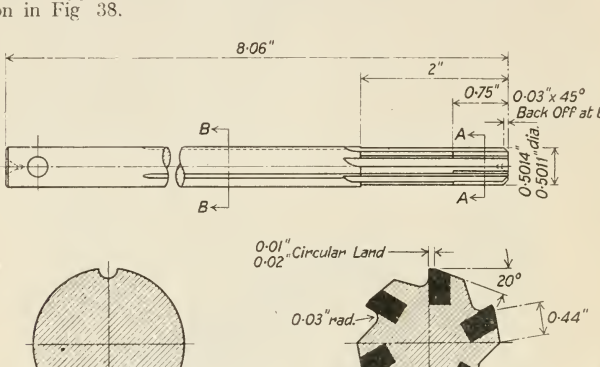


Fig. 40. Reamer for Bronze Bushes

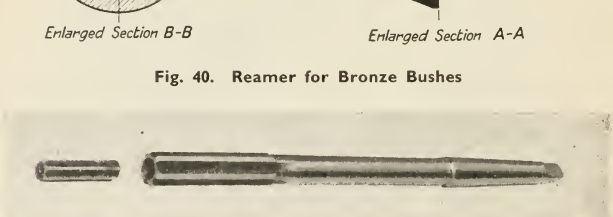


Fig. 41. Wimet Expanding Reamer

A boring cutter with a piloted body is shown in Fig. 39. The blades are locked in a tapered slot one side of which is serrated. The base of the blade is also serrated and fits into the slot. Other cylindrical cutters may be made up by this method.

For boring tools, a circular land of 0·025-inch for diameters up to $1\frac{1}{2}$ inches and increasing to 0·050 inch for larger diameters is suitable for cast iron, brass and bronze. A smaller land is required for materials such as copper, aluminium and plastics. A back taper of 0·001-inch

per inch is suitable for cast iron, etc., increased to 0·0015-inch for the softer materials. A back taper of 0·005-inch per inch on the steel body is sufficient for most purposes. Fig. 40 shows a reamer for sizing bronze bushings.

An expanding reamer made by A. C. Wickman Ltd., and having inserts of Wimet on each flute is shown in Fig. 41. An increase of approximately 0·004-inch on diameter is obtained by gradually tapping in a serrated plug with a light copper- or brass-faced hammer. The

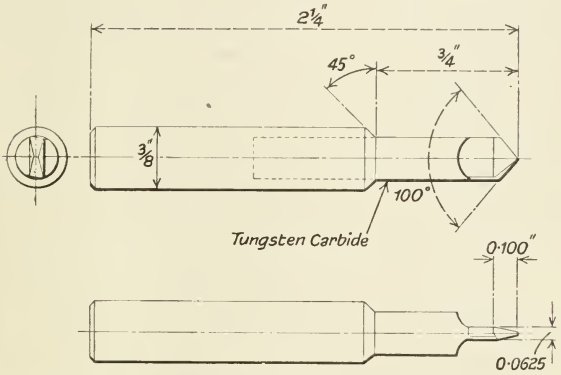


Fig. 42. Drill for Hardened Alloy-steel Camshafts

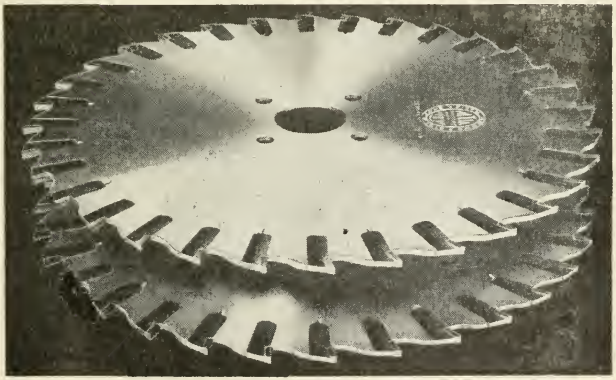


Fig. 43. Mitia-tipped Circular Saw for Aluminium Alloy (Firth-Brown Tools Ltd.)

shank of the reamer is made of nickel steel. On a particular job, 3,000 components were reamed with this type of reamer before regrinding of the carbide blades became necessary. At the top of the illustration is shown a reamer with the plug disengaged from the bore of the reamer body.

Cemented-carbide tipped drills have been used successfully for many years for drilling material such as glass, marble and plastics. They have not, however been successfully used for drilling metals, apart from cast iron and hardened steel. The torsional forces involved in drilling the chip-forming metals are too great for the carbide to withstand. However, a design of drill which has been used in the drilling of hardened alloy-steel camshafts is shown in Fig. 42.

A particular use in drilling of cast iron with cemented carbides is found in preparing samples of cast iron drillings for chemical analysis where it is particularly necessary to avoid contamination.

Fig. 43 shows a tipped circular saw which is used for cutting aluminium alloy at a peripheral speed of 3,000 ft. min. The saw is 32 inches in diameter with a tooth pitch of 3·14 inches.

CHAPTER 3

METHODS OF MOUNTING TOOL TIPS

The majority of cemented-carbide manufacturers list both complete tools and tips. Since it is usually necessary for the user to provide regrinding facilities, it is often more expedient and economical for the user to purchase tips and to manufacture the tools in his own works. The more simple types of tool should present no difficulty provided that a few well-defined precautions are taken.

THE SHANK.—It has been found from experience that the most suitable material is a 0·5 per cent. carbon steel, a quality which is generally known as "shanking steel." Mild steel is not sufficiently stiff for general turning tools although it may be used in an emergency for finishing tools and where the chip load is small. Alloy steels may be used but they do not braze so satisfactorily as the plain carbon steels. High-tensile cast iron such as Meehanite is also used, especially for tools such as solid milling cutters which would normally be made from a steel forging. It is claimed that its greater damping capacity makes cast iron a more suitable material for shanks than steel.

The shank is cut to length, and for cranked tools the neck is hot-forged or bent cold. Front and side clearances are now milled or shaped, whichever is the more convenient, on to the end of the shank. All shank angles are made 2 to 4 deg. greater than the corresponding top, front and side rakes. This ensures that only the carbide is ground after brazing, thereby speeding the grinding operation and preventing undue wear of the grinding wheels.

The base of the seating is milled in the shank at the same angle as the top rake, so that the tip which has parallel top and bottom surfaces, is tilted at the required angle. This is indicated in Fig. 1 where the shape of carbide tip is also shown by orthographic projection. When the seatings are being milled, care must be taken to ensure that the base is flat and that the tip is a good fit without rocking, otherwise the tip may crack in service. The tip surfaces which are to be brazed are ground with a silicon-carbide wheel in order to remove the thin surface layer which is produced during sintering and which is not readily "wetted" by the brazing alloy. There should be an adequate seating chamfer on the edge of the tip and care must be taken that the seating radius is a snug fit in the shank.

The three metals used for brazing are copper, Sif bronze and silver solder. Copper gives the strongest joint, but it is necessary to use a controlled-atmosphere furnace because of the oxidation at the high temperature which is necessary to melt the copper. Sif bronze requires

a slightly lower temperature and can be used successfully for torch brazing. Silver solder has a much lower melting point and is probably the most satisfactory brazing metal to use in small toolrooms as it is simpler to use.

There are several types of furnaces suitable for brazing of carbide tools. Gas and electric furnaces, specially designed for this purpose, and usually arranged with a gas curtain to maintain a reducing atmosphere to prevent oxidation and scaling, are marketed by several of the furnace manufacturers. Bright brazing, in which the tip is wired on to the shank and heated with copper in a reducing atmosphere until the copper melts can be used where the quantity of tools justifies the continuous operation of a furnace.

The use of heating by means of a high-frequency current is now coming into increasing use and offers many advantages, especially in

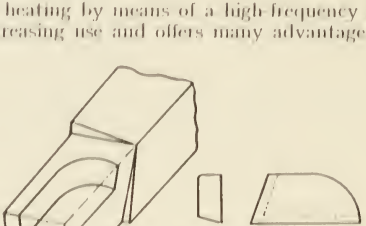


Fig. 1. The Base of the Seating is Milled in the Shank at the Same Angle as the Top Rake

the brazing of intricate tools, where it is necessary to avoid distortion or to keep the main body of the shank in a heat-treated condition. The brazing temperature is reached so rapidly that it is possible to localise the heating in the region of the seating and tip. Here again, the equipment is expensive and can only be justified when a large output of tools is required. High-frequency equipment designed for tool tipping is now manufactured. This consists of either a spark-gap oscillator or a half-megacycle frequency valve oscillator with the necessary heating coils.

A resistance welding machine specially designed for brazing tipped tools has much to recommend it for medium-sized shops using numbers of tools of the same size. The welder is quick, clean and easy to operate. Its main disadvantage lies in the heavy single-phase electric current which is required to run it.

Torch brazing with an oxy-acetylene blow pipe is the best method for the average tool room not dealing with large quantities of cemented carbide tools. Little equipment is required other than a torch, pipes,

the regulating valves and the brazing material, which is preferably silver solder.

Whichever method is used, the seating, tip and brazing alloy must first be thoroughly degreased by carbon tetrachloride or trichlorethylene. A flux is necessary to remove oxides formed on the tool shank during the heating. Borax should be used as flux for copper, and in the case of Sif bronze and silver solder, the flux recommended by the makers. It is best to apply the flux as a thick paste to the seating and the part of the tip which is to be brazed.

Brazing Procedure

When Sif bronze is used the procedure is as follows. Some powdered flux is put on the seating, the shank is pre-heated to about 700 deg. C. (bright cherry red heat), and a little more powdered flux is

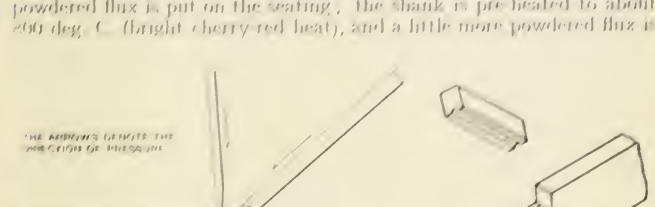


Fig. 2 (left). Method of Pressing the Carbide Tip down on to the Shank during Brazing

Fig. 3 (right). Strengthening the Joint of a Parting Tool by Grinding Grooves in Tip and Seating

added. Next, the temperature of the end of the shank is raised to about 1,050 deg. C., and the tip is placed in position. A piece of Sif bronze welding rod is pressed firmly against the tip, and when the tip has become sufficiently hot the Sif bronze will melt and flow between the tip and the shank. The tip is now pressed firmly into the seating, as shown in Fig. 2 to squeeze out excess brazing material from the joint, and the tip is allowed to cool slowly in dry carbon dust.

When copper is used, a thin sheet of copper 0·010 inch thick is covered with flux and placed underneath the tip which is then placed in the seating. Pre-heating and heating to brazing temperature, in the case of copper, should be carried out in furnaces with a protective atmosphere, to avoid excessive oxidation. A slightly higher temperature, 1,120 deg., is required when copper is used. Copper gives a stronger joint than either Sif bronze or silver solder and is recommended for tools such as parting tools where the area of contact of the brazed joint is small. The joint can be strengthened by grinding a small groove in the tip and seating as shown in Fig. 3.

Silver solder is useful for brazing tips on to complicated shanks which are liable to distort when heated, or where it is desired to leave the shank in a heat-treated condition. Heating may be localised if necessary by burying the main part of the shank in wet sand, leaving exposed only that part which is to be tipped. It is a particularly useful alloy to use when torch brazing, as it only needs a temperature just above 700 deg. C.

For silver solder the green flame of the oxy-acetylene torch is used. This flame is reducing and will not therefore cause undue scaling of the shank. The torch is kept on the move to avoid heating in one spot as localised heating may crack the tip. The torch is first applied at some distance back from the tip and, as the shank becomes heated, the torch is brought forward under the end of the shank. When both the tip and shank have reached a dull cherry red, silver solder rod is pressed on to the tip until the end of the rod is melted and the tip is pushed into position, at the same time excess silver solder is squeezed out. The tool is then allowed to cool off slowly.

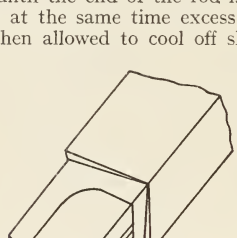


FIG. 4

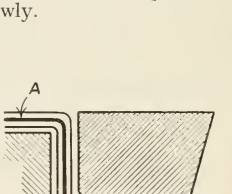


FIG. 5

Figs. 4 and 5. Placing Inserts in the Joint to reduce Brazing Stresses

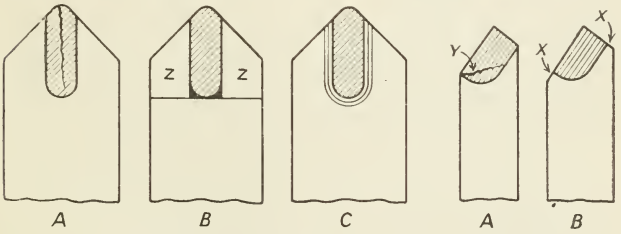
It is important to remember that there is an appreciable difference between the co-efficients of thermal expansion of cemented carbides and steel. The co-efficients of expansion for various relevant materials are given below:

MATERIAL.	CO-EFFICIENT OF EXPANSION.
Steel	14–15 × 10^{-6} per deg. C.
Cast Iron	12 ,, ,, ,,
Steel-grade cemented carbide ..	6·5 ,, ,, ,,
Cast-iron grade cemented carbide..	5·5 ,, ,, ,,

When a cemented carbide tip is brazed on to a shank, stresses are set up due to the difference between the expansion rates of the two materials. The straight tungsten-carbide grades used for cast iron and non-ferrous materials are better able to withstand these brazing stresses than the carbides used for machining steel. Brazing stresses are usually shown up during grinding, as cracks running parallel with the joint.

Obviously the greater the temperature used for brazing the greater the stresses produced. For this reason silver solder is the best material to use on long thin tips such as reamer blades, and on tips having a sudden change of section as in some form tools.

Brazing stress on the tip may be reduced by placing a thin sheet of suitable material between the tip and shank as in Fig. 4. One method of overcoming cracking due to brazing is to insert a sheet of iron gauze between the tip and the shank. This should be done with all tools where the tip is longer than 1 inch on its largest dimension. Tinned 40-mesh iron gauze *A*, Fig. 5, is placed between two sheets of copper *B* and the brazing is carried out in the usual way. Another method is to place a number of fine copper tubes underneath the tip and braze with Sif bronze. If trouble is experienced with brazing stresses, even when using silver solder, a thin sheet of Constantan or Ferry (a nickel-iron



Figs. 6 and 7. Methods of Preventing Cracks

alloy) from 0·003 to 0·006-inch thick may be used with sheets of silver solder, the brazing being carried out as usual. The harder grades of tip used for machining are particularly susceptible to cracking and should always be brazed by one of the methods described. Many production engineers claim that the use of shims in brazing improves tool life.

A method of tipping has been developed in which the tips are screwed or clamped on to the seating of a turning tool, or are wedged in slots in the milling cutter body. Milling cutters tipped in this way have been described in Chapter 2.

Some types of seating cause trouble due to a thin section of steel at the brazed joint, producing cracks as shown at *A* in Fig. 6. This may be avoided by brazing steel inserts *Z* as in *B* or by using a sandwich braze as at *C*. Cracks attributable to the same cause may develop at *Y* in the tool shown at *A* in Fig. 7. Increasing the width of the shank, as at *X* in *B*, will provide a thicker backing and overcome the trouble.

On some tools, such as spot-facing cutters where the tip does not seat up against a shoulder, difficulty may be found in brazing the tips

accurately in the seating. This may be overcome by fitting a graphite plug in the bore and locating the tips off the plug.

Small-diameter tipped reamers are difficult to braze because all of the seatings heat up at once. The tips may be wired in position as

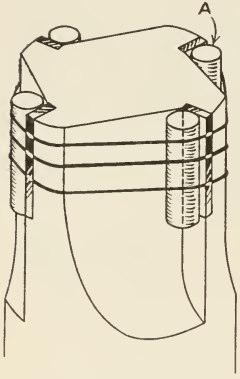


Fig. 8. Wiring Tips in Position on Small-diameter Reamers. Charcoal or Carbon Cylinders are placed as at A and the tips held in position by wire.

shown in Fig. 8 using charcoal or carbon cylinders as shown at *A* and then heated with a torch.

The cylindrical cutters shown in Figs. 36 and 37 of Chapter 2 sometimes cause trouble because the tips protrude into the bore. This may be overcome by fitting a graphite plug into the bore to prevent the tips protruding.

CHAPTER 4

GRINDING AND LAPPING OF CARBIDE

The methods of grinding high-speed steel and other cutting alloys are totally unsuited to the grinding of cemented carbides. It often happens that a grinder experienced in high-speed steel grinding is slower to pick up carbide grinding than a completely " green " operator. Carbide grinding is a slow process and attempts to speed it up by crowding the cut will usually result in cracked tips. On tool and cutter work especially it is important for the operator to know the " feel " of his machine by hand feeding and listening for the " ring " of the grinding wheel.

For successful carbide-tool making, experience of the special technique in grinding cemented carbides is necessary. Cemented carbides are brittle, very much harder, have a lower thermal conductivity than the steel cutting alloys and consequently are much more difficult by ordinary tool-room methods to grind without cracking. However, once the special technique called for is mastered, no particular difficulty should be experienced.

Cemented carbides cannot be ground satisfactorily with the ordinary aluminium-oxide wheels used for grinding steel tools. The aluminium-oxide grains are not hard enough and in consequence are quickly dulled, thus leading to localised heating and cracking of the tool tip.

For grinding cemented carbides, silicon-carbide wheels (the so-called green-grit wheels) are used, followed by diamond-impregnated wheels for finish grinding and lapping.

The importance of correct cutting angles has already been stressed in a previous chapter. It is important, therefore, to see that these angles are maintained on the tool throughout regrinding.

The Grinding Machine

The requirements of a machine for the off-hand grinding of lathe tools are that the spindle should be in good condition and free from end play. The tool fixture should be fitted with a graduated scale and capable of adjustment to any required angle. If wet grinding is to be employed, the supply of water must be ample for the job. Machines specially developed for grinding carbides have three or four wheels and bench or floor stands. A useful machine for average tool rooms consists of three wheels: a straight 14-inch wheel for grinding the carbide

and shank ; a 14-inch cup wheel for semi-finishing ; and a 6-inch diamond-impregnated wheel for final grinding and lapping. A machine of this type is illustrated in Fig. 1. This is made by F. E. Rowland & Co. Ltd., Reddish, Stockport. A larger machine which is specially useful for dealing with large tools is illustrated in Fig. 2. This, made by the Lumsden Machine Co. Ltd., Gateshead, is equipped with four special cup wheels ; one of aluminium oxide for roughing the shanks ; one for roughing the tip ; a semi-finishing and a finishing wheel.

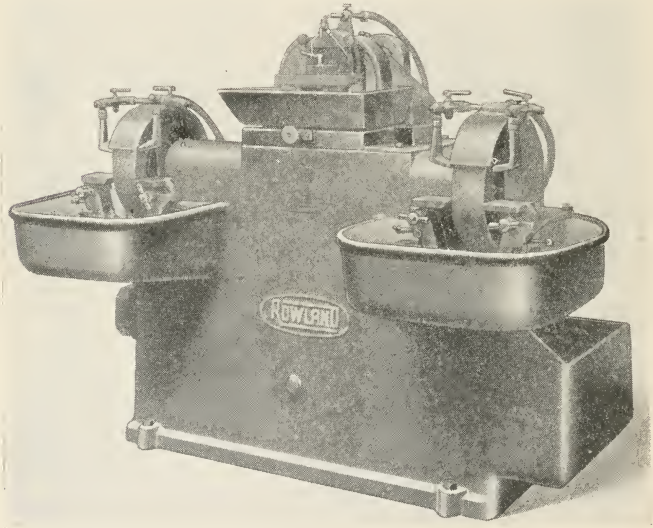


Fig. 1. A 3-wheel Grinding and Lapping Machine

Standard tool and cutter grinders and surface grinder can be used for grinding cylindrical and other special tools. It is an advantage, on tool and cutter grinders, to use some means of varying the spindle speed in order to maintain a nearly constant peripheral speed for the grinding wheel. Surface grinders should be equipped with a quick table traverse

The Grinding Wheel

The silicon-carbide wheels which have been found most satisfactory for carbide grinding are made with a soft bond so that the wheel

structure at the surface breaks down as soon as the particles become worn and dull, thus keeping the wheel in free-cutting condition. In ideal conditions of grinding, the wheel is virtually self-dressing. The proper selection of the grit and grade of the wheel is of vital importance for efficient grinding. The peripheral speed generally recommended by the grinding-wheel manufacturers is from 4,500 to 5,000 ft. per min.

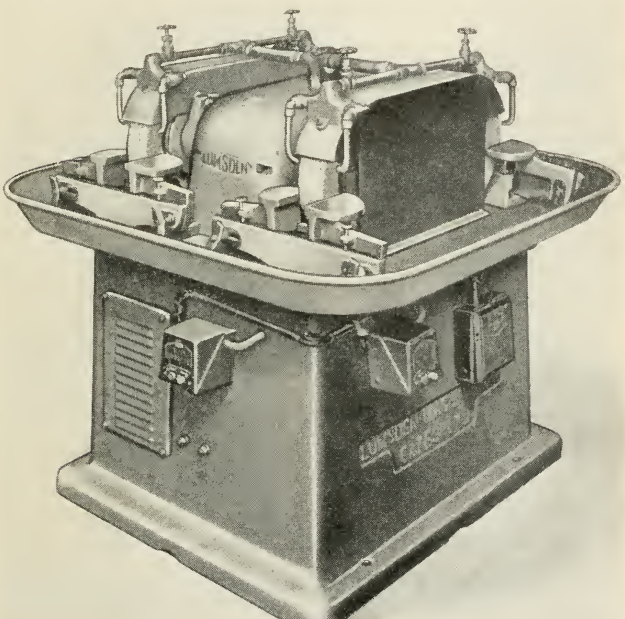


Fig. 2. A 4-wheel Grinding and Lapping Machine

With a well-designed grinding spindle running under good conditions it is possible to lower this speed to 2,500 ft. per min. without impairing grinding efficiency. The more rigid the grinding spindle, the more open and softer is the wheel that can be used. As with steel grinding, increase of peripheral speed has the same effect as using a harder wheel. It is important to hold a speed found suitable for any given operation, hence a variable speed motor is a great asset. The grades of carbide mixture which have titanium added (for use in the machining of steel) are more difficult to grind without cracking than the straight tungsten-

carbide/cobalt mixtures, and particular care must be exercised in the selection of grinding wheel and speeds for steel-cutting tools.

Soft wheels are cool cutting and fast grinding, and should be generally used for off-hand grinding. The larger the arc of contact, the coarser and softer should be the wheel. Hence, for cup wheels and wheels of a large diameter a soft bond is required. For surface grinding and form grinding it is necessary to use a harder wheel that will not lose its form so rapidly. These need to be kept free-cutting by frequent dressing with a diamond. Considerable experience is needed if harder wheels are to be used satisfactorily without cracking the tip. This applies especially to the steel-cutting grades of carbide.

It is best to use wet grinding wherever possible. This enables a harder wheel to be used, and the wheel does not load up so easily; also the tool is kept cooler. It is important to maintain a copious stream of coolant. A trickle of water on the tool merely causes local cooling which inevitably leads to a cracked tip.

On the other hand, dry grinding, which is used to a very large extent, can be satisfactory. When, during the application of dry grinding, a tip becomes heated by the grinding wheel, it must not be cooled suddenly in water, or cracking will almost certainly occur. The shank however may be cooled in water.

The proper grinding conditions are really a compromise which can only be learnt by experience. For this reason it is best to train operators for this job rather than leave regrinding to machine operators.

General recommendations for green-grit grinding wheels are as follows :—

Roughing : Silicon carbide 158E.
Finishing : Silicon carbide 162D.

Grinding Single-point Turning Tools

A satisfactory method of off-hand grinding and regrinding lathe tools in a small tool room, using the 3-wheel grinder described on page 48 is as follows :—

On this machine, the 14-inch peripheral wheel is used for rough grinding, the 14-inch cup wheel for finish grinding, and the 6-inch diamond lap for final grinding and lapping. It has already been mentioned that in order to remove the carbide rapidly with cool grinding, the arc of contact between the tool and the wheel must be kept small. For this reason, the edge of the peripheral wheel and the face of the cup wheel are crowned as shown in Fig. 3 with a Huntingdon or star dresser. The front and side clearances of the tool are now ground on the peripheral wheel, keeping the angles about 2 deg. larger than finally required. Throughout the operation the tool must be kept constantly on the move. The shank and tip are ground alternately. Thus when the wheel becomes clogged with steel from the shank it is

possible to use the tip to dress the wheel again. If the wheel shows signs of glazing it is redressed with a Huntingdon dresser. If the tip has been badly chipped it must be ground away as shown in Fig. 4. The tool is next applied to the cup wheel which is also crowned with a dresser as shown in Fig. 3. The table is set to the final clearance required and, if necessary, the top face is ground, followed by the side and front faces. The top face should always be ground first and then front and side clearances with the wheel grinding on to the tip as

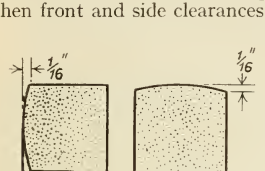


FIG. 3

FIG. 4

Fig. 3. Showing how the Wheels should be crowned
Fig. 4. The Broken Tip and Method of Regrinding it

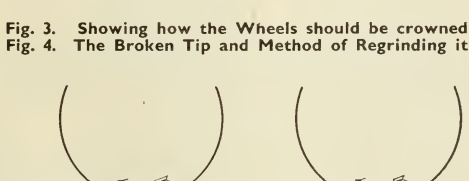


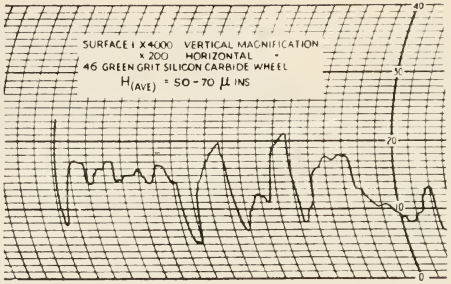
Fig. 5. The Top Face should always be Ground First

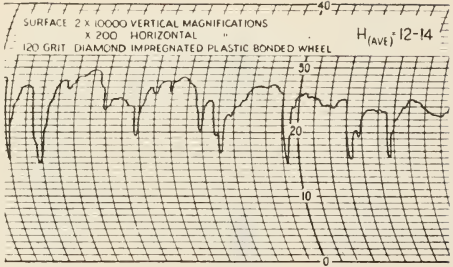
shown on the left in Fig. 5. This prevents chipping along the edges.

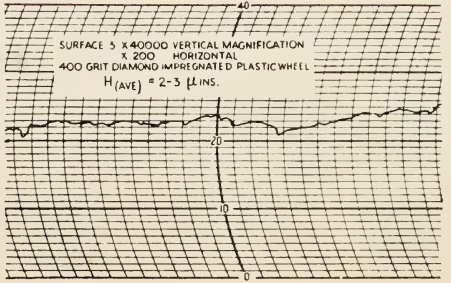
For large shanks it is best to use an aluminium-oxide wheel, as used for grinding steel, to remove the major portion of the steel and then a green-grit wheel to finish the grinding. The final grinding will be done with a 120/150 diamond-impregnated wheel.

Diamond-impregnated Wheels

The silicon-carbide wheels are at best a compromise between rapid cutting and heavy wear. Although the silicon-carbide wheel can be used successfully for the major part of the grinding operation, and indeed for many machining jobs the finish produced is adequate, there is a need for a harder abrasive than silicon carbide to complete the grinding operation. Diamond in the form of powder set in a suitable matrix is the abrasive which has been found to be easily the best for this purpose. The diamond used in this type of industrial stone known as Bort, which







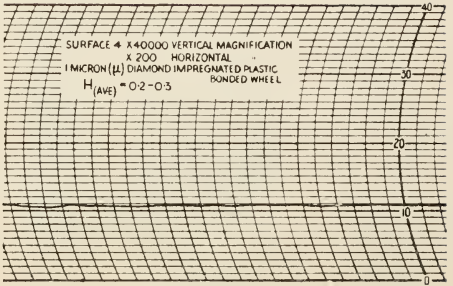


Fig. 6. Talysurf Diagrams demonstrating the Improved Surface Finish of the Tool due to Diamond Lapping

is crushed, and carefully graded and set in a matrix. Plastic diamond-impregnated wheels are most generally used. Metal-bonded wheels are being used at an increasing extent as they do not wear so quickly as the plastic wheels. Diamond dust set in vitrified matrix, *i.e.* with a similar bond to an ordinary green-grit wheel, is being developed and may possibly replace the other two forms of diamond wheel in the future.

The diamond, being considerably harder than tungsten carbide, has quite a different cutting action to that of silicon-carbide. Since the

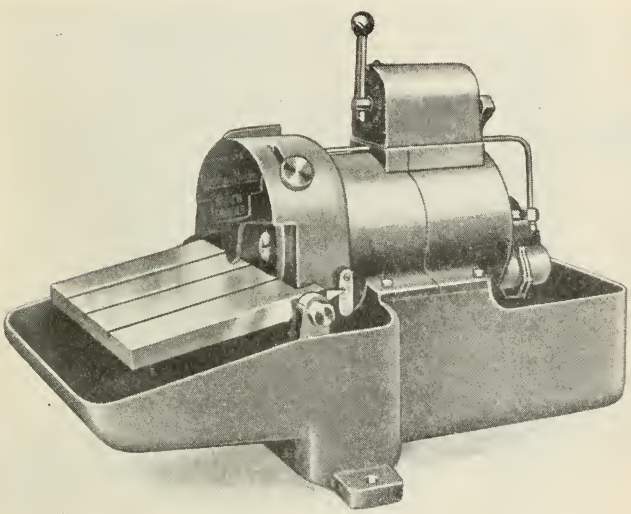


Fig. 7. A Compact Bench Grinder which uses a Diamond-impregnated Wheel

wheels are free-cutting there is no necessity to crown the periphery and the risk of cracking the carbide is very much reduced. Thus less skill is required to use the diamond wheel than the original green-grit wheel. It has been definitely proved that diamond lapping improves the life of a tool between regrinds, especially on finishing cuts. On operations where the feed is light and the depth of cut is small, it is particularly important to diamond-lap the cutting edge, and it may be worthwhile polishing the small land along the cutting edge with a finer grit diamond wheel. In the majority of finish-grinding operations, a 120/150 grit diamond lap is adequate. Improved finish may be achieved with 200/250 grit wheel and it is possible to polish carbide using a 350-grit diamond wheel. A marked improvement in surface finish on tungsten carbide is strikingly shown in the Talysurf Surface Analyser diagrams in Fig. 6.

For off-hand grinding, several compact machines are on the market, using diamond-impregnated wheels. A typical machine, the Wickman-Neven G.F.2, a bench mounting machine, is illustrated in Fig. 7. This is made by A. C. Wickman Ltd., Coventry, and is fitted with a reversible motor and adjustable tool rests. The plastic wheels are best used with a good flow of coolant, although on machines where this is not convenient, such as tool-room cutter grinders, a felt pad soaked in light

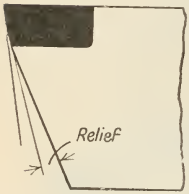


Fig. 8. Secondary Relief recommended if the Tool Cutting Edge is to be lapped with a Fine-grit Wheel

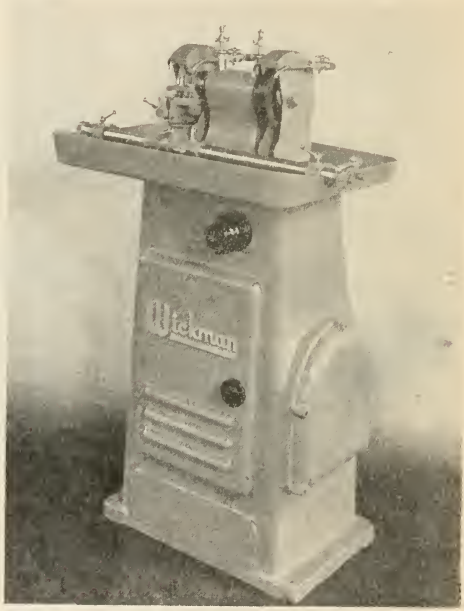


Fig. 9. Wickman Agathon Machine for Precision Lapping

machine oil or paraffin may be used. Metal bonded wheels show a greater tendency to glazing than plastic wheels and should always be used with a good flow of lubricant. The wheels may be dressed with an abrasive stick or pumice. Wheels which are badly grooved can be reconditioned by lapping with carborundum powder on a flat piece of plate glass.

For off-hand grinding, the recommended peripheral speed is the same as for silicon-carbide wheels, using a hand pressure of from 5 to

7 lbs. The wheels quickly become more clogged if they come in contact with the steel shank. It is particularly important, therefore, to see that the shank is adequately backed off by at least 2 deg. If the cutting edge is to be lapped with a finer grit, a secondary relief as shown in Fig. 8 should be used.

Care is necessary in generating the nose radius to avoid producing a groove in the face of the wheel. The metal-bonded wheels are better

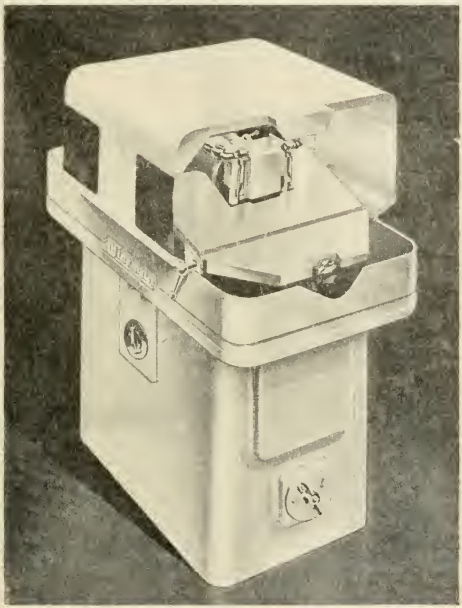


Fig. 10. The Wickman Type 8B Grinding and Lapping Machine

than the plastic wheels in this respect because the tool does not dig into the face of the wheel so easily.

A very convenient machine for which diamond-impregnated wheels are recommended is the Wickman Agathon shown in Fig. 9. This has been designed for grinding and lapping modern carbide tools, including special tools used in the screw-making and instrument industries. It is a 2-wheel machine, one wheel for preliminary grinding and the other for finish-grinding or lapping. The tool rest slides on a hardened

and ground bar, whereby the tool can be transferred from the grinding to the lapping wheel, without reclamping. Fine micrometer adjustment is provided to the tool rest, so that a controlled pressure of the tool against the wheel is obtained.

A comparatively recent machine is the Wickman, Model 8B, 8-inch grinding and lapping machine shown in Fig. 10. This is a self-contained unit occupying a floor space of 42 × 34 inches. The wheel covers, a special outer splash screen and tray are designed to prevent coolant leaving the machine. Rubber flaps forming part of the screen can be pushed back when cranked tools are being ground. The motor spindle can accommodate either Spedia or Neven diamond wheels, or the usual grinding wheels.

CHAPTER 5

THE APPLICATION OF CEMENTED-CARBIDE TOOLS

Previous chapters have dealt with the various factors which have to be considered in the design and manufacture of cemented-carbide tools. The present chapter will deal with the more important points to be observed during machining operations in which carbide tools are employed.

Good carbide-tool design aims at exploiting to the full the high cutting capacity of the carbide, and at the same time takes into account the brittleness and low tensile strength of carbide. A machine in bad condition or under-powered, however, can very easily damage the best of carbide tools, hence great care must be taken in their use.

Once the rate of metal removal has been determined, the necessary horse power can be calculated. The drive, however, must be capable of transmitting the load without slip, since stalling under the cut will, in almost every case, cause damage to the tool. For the same reason, the feed should always be disengaged before the machine is stopped. Should the machine stall with the feed engaged, the power should be cut off, and the tool retracted from the workpiece.

The extreme importance of using the correct tool angles, in order to get the best cutting efficiency has already been stressed. Just as important is the correct setting of the tool to the work. The tool should be set in the tool post so that the nose of the tool is on the centre of the work. When the tool is set above centre, the effective top rake is increased, and the front clearance is reduced, resulting perhaps in ineffective cutting. Setting the tool below the centre reduces the top rake and increases the chip pressure on the top of the tip. This may cause collapse of the cutting edge, because with a tool cutting below centre, the front clearance is greater than necessary.

For tools designed for use with negative top rake, the centre line of work should be slightly lower than the middle point of the cut.

As regards tool clamping, the tool po t must be capable of holding the tool very firmly, and as close to the work as is practicable. A flat-bottomed tool post fitted with blunt-ended clamping screws is best. With this type of tool box it is a simple matter to pack up the tool to the required height with shims. The rocker-type of tool holder should be avoided, since it does not give adequate support to the tool. If, however, there is no alternative, the tool must be kept horizontal, preferably by turning the post collar upside down.

Overhang of the tool from the tool post should be as small as possible. If however, the tool layout calls for a large tool overhang, tool life can be improved by increasing the depth of shank.

When the tool is being set in the tool post, its edge must not come into contact with the workpiece, nor must the tool be shifted by blows from a hammer or spanner. It is surprising how often one sees this kind of "carbon-steel" treatment meted out to carbide tools.

Since carbide tools are usually operated at higher speeds than are usual with tool steels, it is very essential that careful attention should be given to the fixtures holding the workpiece. Also where the work to be turned is supported on a centre or centres, these should be of the running type since fixed centres usually become overheated at high speed. For lights cuts, however, carbide-tipped centres will be found satisfactory, and for turning long slender workpieces a travelling steady rest may be found necessary, to reduce danger of deflection.

Speed, Feed and Depth of Cut

Speed.—Carbides generally require high peripheral speeds, and this speed is a very critical factor in determining tool life between regrinds. It is best therefore, to try and fix the cutting speed before deciding the feed and depth of cut. Tool performance is greatly affected by the speed at which the chip passes over the cutting edge. A useful formula for converting rotational speed (revolutions per minute) into surface speed (ft. per minute) is

$$\text{r.p.m.} = \frac{\text{surface speed} \times 3{\cdot}82}{\text{diameter of workpiece (inches)}}$$

The diameter is measured on the unturned portion of the work.

Tables of feeds and speeds are given in the following chapter for a range of workpiece materials when cut by certain well-known brands of carbide. The figures given are those recommended by the carbide makers. It will be found in practice that a reasonable margin exists in cutting speed. The speed is, however, more critical with steel, or with metals producing a type of chip similar to that from steel.

When steel is machined at too low a speed, a built-up edge develops on the carbide tool. This consists of laminated fragments of steel from the workpiece which become welded together and to the cutting edge, thus forming a lip on the top face of the tool, and causing an alteration in direction of the cutting forces. The result of this may be a complete collapse of the cutting edge, or the built-up edge may break down and reform intermittently, thus resulting in a very poor surface finish and short tool life.

Increase of speed will reduce and finally eliminate the built-up edge. Excessive speed will, however, cause the cutting edge to burn and wear away rapidly. In practice, a compromise has to be effected in the matter of speed. A rate of 200 ft. per min. or over is usually a

safe general speed for steel. In the case of cast iron and non-ferrous materials the speed is not so critical.

Feed.—When a satisfactory cutting speed has been arrived at, the question of feed must next be settled. The feed should always be sufficiently coarse to ensure that the tool is cutting and not rubbing. A safe general rule is 0·010- to 0·020-inch per revolution. Where it is essential to reduce the feed to a value below 0·010-inch, special attention should be given to lapping the cutting edge by fine diamond wheels, since a fine feed puts more wear on the cutting edge.

In certain applications, such as fine boring, it may be necessary to use a feed as low as 0·002-inch per revolution, in order to get the required surface finish. In such cases, polishing the cutting edge will give results which will, in most instances, easily justify the extra trouble involved.

When steels have to be machined, chip disposal is an important factor in fixing the rate of feed.

Depth of Cut.—The depth of cut is generally determined more by other factors in the machining operation than any physical limitation in the tool itself. For roughing, the depth is mainly limited by the power available on the machine tool. The power used at the tool cutting edge is approximately given by the formula:

$$\text{Cutting horsepower} = 1{\cdot}86 \times f \times t \times s$$

where d = depth of cut, measured in thousandths of an inch; f = feed measured in thousandths of an inch per revolution; t = tensile strength of the material cut, in tons per sq. in; and s = cutting speed in ft. per min.

An increase of up to 25 per cent on a figure obtained from this formula will probably be required for negative-rake turning.

The formula does not allow for the power which is not used by the tool and which is roughly equal to the power taken by the machine when running light.

Rigidity of the cutting tool, the machine, the chuck and all holding fixtures also affect the depth of cut which may be safely taken. It is sometimes an advantage to increase the depth of cut at finishing in order to reduce the load during roughing. For instance, in removing $\frac{3}{8}$-inch total material from a workpiece, it would normally be best to take a $\frac{5}{16}$-inch roughing cut and follow by a $\frac{1}{16}$-inch finishing cut, using a harder grade of carbide for the finishing tool. If, however, the machine is not able to withstand the load for the roughing stage, or the job does not warrant the employment of a special carbide, a roughing cut of $\frac{1}{4}$-inch can be followed by a finishing cut of $\frac{1}{8}$-inch, both being carried out with a general-purpose grade of carbide.

It is important in roughing that the depth of cut is sufficient to keep the nose of the tool underneath the surface scale. Trouble is often experienced in roughing steel castings, due to insufficient machining allowance causing severe wear on the cutting edge. The normal

grades of carbide used for steel cutting are not usually successful in resisting the abrasive action of scale on castings. In such cases, the grades of carbide used for cast iron will be found to effect an improvement.

Wherever possible, it is advisable to maintain a depth of cut of at least 0·005-inch on finishing. A very shallow cut concentrates the work at the nose of the tool, consequently the nose overheats and wears away rapidly. Should, however, a shallow cut of 0·002 inch be necessary, particular attention should be paid to maintaining a good finish to the cutting edge.

Coolants when Cutting

The best all-round coolant for carbide tools is soluble oil. A coolant is recommended for increasing tool life and maintaining a constant surface finish. One of the outstanding characteristics of the cemented carbides, however, is their ability to retain a cutting edge at high temperatures. It often happens that the advantages of cutting dry, in spite of a shorter tool life, outweigh the disadvantages of the use of a coolant.

The same remarks apply to the use of a coolant for cutting as when the wet grinding of carbide tools was discussed. It is vital to use plenty of coolant applied at a high velocity right at the nose of the tool. If necessary two jets of coolant must be used; at all costs a trickle must be avoided. It is the alternating localised cooling and heating which causes cracking of the tip. It is far better to machine dry if it is not possible to use coolant satisfactorily.

Tools should be removed for regrinding before they have reached the maximum number of components per grind. In this way it will be necessary to grind back a comparatively small amount of the tip. It is extremely wasteful of carbide to continue to use the tool to the point at which collapse of the cutting edge occurs.

In spite of all the precautions which have been taken in tool design and manufacture, choice of carbide grade, machine set up, etc., troubles will still be met which can only be satisfactorily settled by a method of trial and error on the actual machining job.

Much of the trouble can be traced by a careful examination of the cutting edge of the tool. A small watchmaker's glass will be found very useful, especially in detecting the difference between minute cracks and wear of the cutting edge.

If the cutting edge wears rapidly the feed should be checked. A light feed, especially when machining material with a springy chip, produces a tough thin ribbon of swarf which is moving rapidly across the cutting edge. A heavier feed will move the point of contact in from the cutting edge slightly. If it is not practicable to increase the feed, the way in which the tip has been ground should be examined. A

narrow diamond-lapped finish to the cutting edge may cure the excess wear. If the nose radius of the tool is too large, a thin chip is produced which will cause abnormal wear, especially on the end of the tool. Too small a nose radius will also cause rapid wear. This usually shows as actual burning or collapse of the end of the tip. A cutting speed which is too high also causes a rapid wear through burning. Insufficient top rake with a fine feed may be the cause of wear. Setting the tool above centre, or inadequate clearance angles, will cause the tool to drag and show signs of bad wear in particularly difficult cases. On castings, wear can often be caused by sand in the skin of the casting abrading the cutting edge. An increase in the depth of cut will help in getting the nose of the tool underneath the skin.

If, in spite of attention to all these points, the wear is excessive, the grade of carbide should be changed. It should be remembered that where wear is due to actual abrasion, the cast iron grades of carbide have a better resistance towards abrasion than most steel-cutting grades.

Excessive wear on the top surface of the tool can be caused by running at a speed which is too low. A heavy feed also gives the same effect. Complete collapse of the cutting edge usually results from continued machining under these conditions. A carbide with insufficient resistance to cratering will first show signs of wear on the top. It sometimes happens that tips which were intended for machining cast iron get made up into tools for steel machining.

Chipping of the cutting edge can very often be traced to bad grinding. The cutting edge should be carefully examined with a watchmakers' glass before the tool is put into use, to ensure that the fault does not lie in the grinding.

With a heavy cut, in roughing a workpiece which is heavily scaled, the chipping can often be stopped by honing a slight negative land. A narrow chip breaker will also cause chipping.

Chatter can be caused by excessive overhang. If the set-up does not permit this to be reduced, the cross section of the tool shank should be increased. Large nose radius will also cause chatter.

CHAPTER 6

SOME PROPRIETARY BRANDS OF CARBIDE

The topics as discussed in the preceding chapters are intended to indicate the nature of carbide-tipped tools and how they can be applied to the cutting of materials. Carbides are made in different grades to suit various workpiece materials and cutting conditions, and the user will wish to select the best grade for his work. Carbide manufacturers have devoted a great deal of time in determining the limitations of their various grades, and it is best to follow the manufacturer's recommendations. The present chapter gives some useful operating conditions for a number of well-known proprietary brands of carbide.

WIMET.—This well-known brand of tungsten carbide is made by A. C. Wickman, Ltd., Coventry, and is available in ten grades as follows :—

Grade XX.—For rapid machining of all kinds of steel, and for the finish turning of steel at high cutting speeds. It is crater resistant.

Grade X8.—A grade that is very successful in roughing steels.

Grade S58.—Used instead of high-speed steel for forgings, castings, stampings, etc., at fairly low speeds. It will stand a top rake of 12 to 15 deg. and operate at coarse feeds.

Grade G.—This is a tough variety, principally for tipping planing tools.

Grade H.—Used for the machining of chilled iron rolls and castings, and for sand-cast hard brass and bronze ; also recommended for synthetic resins, erinoid, etc. Very suitable for fine boring operations, and high-speed machining of aluminium alloys.

Grade N.—This is a general-purpose material and is satisfactory for cast iron, bronze, gun metal, silicon, aluminium, zinc-base alloys, insulating materials, slate and marble.

Grade NC.—This has been produced primarily for wire-drawing dies, but is used for machining when Grade N is insufficiently tough.

Grades T. and TT.—These are for blanking, piercing and drawing tools, heading and extrusion dies, and similar tools used under heavy impact conditions.

Grade NS.—A special grade for machining centrifugally-cast iron.

Speeds feeds and tool angles advised for Wimet are given in Table I.

TABLE 1.—RECOMMENDATIONS FOR WIMET BRAND TUNGSTEN CARBIDE

Workpiece Material	Grade of Wimet	Rough Turning			Finish Turning		
		Speed Ft. per Min.	Feed	Top Rake Deg.	Speed Ft. per Min.	Feed	Top Rake Deg.
28–35 Tons Tensile							
Black Bar Stampings	S.58	200–300	0·078	15	200–350	0·010	15
	X 8	300–400	0·040	8	350–500	0·008	10
Rough Forgings	XX	400–450	0·040	up to 15	600–800	0·008	up to 10
removing scale ..	S.58	200–300	0·050	15	300–350	0·010	15
	X 8	300–400	0·040	8	350–500	0·008	10
	XX	400–450	0·030	8	600–800	0·008	10
Clean Metal ..	S.58	250–350	0·080	up to 20	350–400	0·010	20
	X 8	350–400	0·040	8	400–500	0·010	8
	XX	500–550	0·020	10	600–1000	0·008	8
Castings	S.58	250–350	0·050	15	350–400	0·008	10
	X 8	350–400	0·040	8	400–500	0·008	8
	XX	500–600	0·020	8	600–800	0·008	10
40–45 Tons Tensile							
Black Bar Stampings	S.58	200–300	0·070	15–18	300–350	0·010	10
	X 8	300–400	0·040	8	350–500	0·010	8
	XX	400–450	0·020	10	600–800	0·008	8
Rough Forgings							
removing scale ..	S.58	200–300	0·050	15	300–350	0·010	12
	X 8	300–400	0·040	8	350–500	0·010	8
	XX	400–450	0·020	8	600–800	0·008	10
Clean Metal ..	S.58	200–300	0·060	15	300–350	0·010	12
	X 8	300–400	0·040	8	350–500	0·008	8
	XX	400–450	0·020	8	600–1000	0·008	8
Castings	S.58	200–300	0·060	15	300–350	0·010	15
	X 8	350–400	0·040	8	400–450	0·008	8
	XX	450–500	0·020	5	600–800	0·008	8
55–65 Tons Tensile							
Black Bar Stampings	S.58	180–200	0·060	10	200–250	0·010	10
	X 8	200–300	0·060	8	350–400	0·010	8
	XX	300–350	0·030	8	500–700	0·008	10
Rough Forgings							
removing scale ..	S.58	180–200	0·040	12	200–250	0·010	10
	X 8	200–300	0·060	8	300–400	0·010	8
	XX	300–400	0·030	5	400–500	0·008	5
Clean Metal ..	S.58	150–200	0·040	15	200–400	0·010	15
	X 8	200–300	0·030	8	300–500	0·010	8
	XX	300–500	0·020	5	600–1000	0·010	8
H.S.S. Annealed ..	S.58	80–100	0·040	10	100–150	0·010	10
	X 8	120–150	0·030	5	150–200	0·008	8
	XX	100–200	0·015	5	200–250	0·005	5
Chrome Nickel— 65–95 Tons Tensile							
Black Bar Stampings	S.58	120–150	0·030	10	150–200	0·010	10
	X 8	150–200	0·020	5	200–250	0·010	8
	XX	200–250	0·015	5	500–600	0·008	5
Forgings	S.58	120–150	0·030	10	150–200	0·008	10
	X 8	150–200	0·020	5	200–250	0·008	5
	XX	200–250	0·015	5	500–600	0·005	8
Clean Metal ..	S.58	120–150	0·040	12	150–200	0·010	12
	X 8	150–200	0·015	8	200–250	0·008	8
	XX	200–350	0·015	5	400–900	0·008	5

TABLE I. (*ontinued*)—RECOMMENDATIONS FOR WIMET BRAND TUNGSTEN CARBIDE

Workpiece Material	Grade of Wimet	Rough Turning			Finish Turning		
		Speed Ft. per Min.	Feed	Top Rake Deg.	Speed Ft. per Min.	Feed	Top Rake Deg.
Stainless Steel Castings	S.58	70–100	0·040	10	100–120	0·010	10
	X 8	110–120	0·030	8	120–180	0·010	8
	XX	100–130	0·015	3	130–190	0·008	5
Bar	S.58	100–120	0·040	10	120–150	0·010	10
	X 8	130–160	0·030	5	150–220	0·008	8
	XX	200–250	0·015	3	300–400	0·005	5
Manganese Steel 12 per cent	S.58	40– 70	0·020	8	60– 90	0·010	8
	X 8	50– 80	0·010	3	60– 95	0·005	3
	XX	80– 90	0·008	0	90–120	0·005	0–3
Cast Iron and Non-Ferrous Materials							
Cast Iron, 200 B	N	185–300	up to 0·060	8	350–700	up to 0·010	8
Close-grained Iron	N or H	160–200	0·060	3	250–400	0·008	3
Centrifugal Castings	N or H	135–180	0·060	3	250–350	0·005	3
Chromium Iron	N or H	130–180	0·060	3	250–350	0·005	3
Malleable Iron	N or H	165–210	0·060	8	300–450	0·008	8
10 per cent. Nickel Iron	H	20– 35	0·060	0–2 Neg	25– 45	0·004	0
Pearlite Iron	H	150–250	0·060	0–2 Neg	250–400	0·004	3
Copper	N	500–800	$\frac{1}{32}$	13	750–1000	up to 0·012	13
Cupro Nickel	N or H	350–500	0·020	8	400–600	up to 0·012	8
Soft Brass	N	750–1000	$\frac{1}{32}$	3	750–1000	up to 0·015	3
Hard Cast Brass	H	400–600	0·080	3	500–1000	up to 0·012	3
Bronze	N or H	400–600	0·080	3	500–1000	0·012	3
Gunmetal	N or H	400–600	0·080	3	500–1000	0·012	3
Aluminium Bronze	N or H	300–600	0·060	3	600–800	0·010	3
Admiralty Bronze	N or H	400–600	0·060	3	500–800	0·012	3
Manganese Bronze	N or H	350–400	0·060	3	450–750	0·010	3

(*Table continued on next page*)

TABLE I.—(*continued*) RECOMMENDATIONS FOR WIMET BRAND TUNGSTEN CARBIDE

Workpiece Material	Grade of Wimet	Rough Turning			Finish Turning		
		Speed Ft. per Min.	Feed	Top Rake Deg.	Speed Ft. per Min.	Feed	Top Rake Deg.
minium	H	unlimited	0·030	20	unlimited	0·004	up to 15
on Aluminium ..	H	400–550	0·030	13	500–750	0·004	13
minium Alloys ..	H	unlimited	0·030	13	unlimited	0·005	13
-base Alloys ..	N	600–800	0·030	13	800–1000	0·003	13
alumin	N or H	unlimited	0·030	13	unlimited	0·005	13
tics	N or H	300–600	0·006	0 to 8	300–800	0·003	0 to 8
oid	N or H	300–600	0·006	0 to 8	300–800	0·003	0 to 8
nite	N or H	200–500	0·006	0	200–500	0·003	0
s	N or H	40– 60	Hand Feed	0 to 3	40– 60	Hand Feed	0 to 3
e	N or H	60– 80		0 to 3	60– 80		0 to 3
ble	N or H	60– 80		0 to 3	60– 80		0 to 3
d Rubber ..	N or H	600–800	0·012	0 to 8	600–800	0·008	0 to 8

Boring Speeds : $\frac{3}{4}$ of the above Turning Speeds.

SPECIAL APPLICATIONS

	Grade of Wimet	Feet per Minute	Feed	Depth of Cut	Top Rake	Clearance
dium Rubber ..	N or H	400	0·002″–0·016″	0·003″–0·125″	45°	5°

	Grade of Wimet	Shore Hardness	Rough Turning		Finish Turning	
			Speeds Feet per min.	Feeds	Speeds Feet per min.	Feeds
illed Iron Rolls ..	H	55–65	11–15	2 mm.	20	4 mm.
		70–75	7–10	2 mm.	15	3 mm.
		80–90	3– 6	1 mm.	10	2 mm.

Cutting speeds and feeds for chilled rolls are given only for guidance. ctual performance obtained may vary widely from the given figures, depending n material specification and machine condition.

ARDALOY.—This cutting alloy is made by the British Thomson-Houston Co., Ltd., Rugby and distributed by Alfred Herbert, Ltd., Coventry. It is supplied in the form of tipped tools or as separate tips, in five grades. These are as follows :—

Grade 1A179.—This is for light cuts, and the finish turning of hard cast iron ; for turning chilled-iron rolls and machining aluminium alloys ; Bakelite, and non-ferrous metals ; for tipping reamer and counter-boring blades ; and for fine boring on cast iron, bronze and aluminium alloys.

Grade 2A.—This is for general work on cast iron, malleable iron, semi-steel, non-ferrous materials, for milling cutters used on cast iron, and for work guides of such machines as centreless grinders. It is also used for gauges and micrometer and measuring anvils, and for general-purpose work involving intermittent cutting, *e.g.* planing of cast iron and non-ferrous metals.

Grade S48.—This is a steel-cutting grade, and is for the heavy cutting of steel at medium to coarse feeds. It is recommended for intermittent cutting providing the machine is in a satisfactory condition.

Grade S200.—This also is a steel-cutting grade and is used for milling cutters, for finish turning, and on clean material at high speeds and fine feeds. It also is suitable for general steel work, using medium to high speed and medium feed.

Grade 3.—This is used for making drawing dies.

The makers' recommendation for Ardaloy turning tools with positive rake are given below in Table II. Clearance angles for all tools is 4 to 6 deg. except where marked * which have a rake of 10 deg.

TABLE II.—RECOMMENDATIONS FOR ARDALOY TURNING TOOLS

Workpiece Material	Rough Turning Speed. Feet per minute	Finish Turning Speed. Feet per minute	Top Rake Deg.
STEEL			
28/35 tons tensile—			
Black bar, stampings	250–300	400– 750	3½
Rough forgings—removing scale..	200–300	300– 400	0–3½
Clean metal	250–350	700– 800	8
Castings	250–300	400– 750	0–3½
40/45 tons tensile—			
Black bar, stampings	200–250	500– 600	0–3½
Rough forgings—removing scale..	150–200	200– 300	0–3½
Clean metal	200–300	500–1000	3½
Castings	150–250	250– 350	0
55/65 tons tensile—			
Black bar, stampings	200–250	300– 500	0–3½
Rough forgings—removing scale..	150–200	200– 300	0–3½
Clean metal	200–300	500– 600	0–3½
High-speed steel—annealed	60– 80	150– 250	3½

TABLE II. (*continued*)—RECOMMENDATIONS FOR ARDALOY TURNING TOOLS

Workpiece Material	Rough Turning Speed Feet per minute	Finish Turning Speed. Feet per minute	Top Rake Deg.
STEEL—*contd.*			
Chrome nickel—65/90 tons tensile—			
Black bar, stampings	80–100	250– 350	0
Forgings	80–100	250– 350	0
Clean metal	200–300	500–1000	0–3½
Stainless Steel—			
Castings	60–100	100– 150	0
Bar	100–150	200– 300	3½
Manganese steel—12 per cent.	10– 20	30– 40	0
CAST IRON AND WROUGHT IRON			
Cast-iron—200 Brinell	150–200	300– 400	3½–8
Close-grained iron	150–200	250– 500	3½
Centrifugal castings	120–180	250– 350	3½
Chromium iron	120–180	250– 350	3½
Malleable iron	100–200	250– 400	8
10 per cent nickel iron	20– 30	30– 45	0
Pearlite iron	150–250	250– 400	0
Wrought iron	150–250	300– 500	8
White cast-iron	10– 20	20– 30	0
Chilled-iron rolls	10– 20	30– 50	0
NON-FERROUS METALS			
Copper	500–800	800–1200	13–16
Cupro nickel	350–450	400– 500	3½
Soft brass	500–800	800–1200	3½
Hard cast brass	400–600	800–1000	0
Bronze	400–600	800–1000	0–3½
Gunmetal	400–600	800–1000	0–3½
Aluminium bronze	300–500	600– 750	0–3½
Admiralty bronze	300–500	600– 750	0–3½
Manganese bronze	300–400	450– 650	0
Aluminium	Up to 1000	Up to 2000	13–16
Silicon aluminium	300–500	600– 750	13–16
Aluminium alloys	300–500	600– 750	13–16
Zinc-base alloys	300–500	600– 750	13–16
Duralumin	300–500	600– 750	13–16
NON-METALLIC MATERIALS			
* Plastics	400–600	800–1000	0
* Erinoid	400–600	800–1000	0
* Ebonite	400–600	800–1000	0
* Hard Rubber	400–600	800–1000	0
Porcelain	10– 30	40– 65	0
Glass	30– 50	50– 70	3½
Slate	50– 80	80– 100	3½
Marble	10– 30	40– 65	0–3½

CUTANIT.—This grade of carbide is manufactured by Cutanit Ltd., 2, Caxton Street, London, S.W.1. The angles recommended for Cutanit turning tools are as given in Table III. These figures should be employed in conjunction with the speeds given in Table IV. The feeds and depths of cut are given in Table V.

CUTANIT — This brand of cemented carbide is supplied exclusively by William Jessop & Sons, Ltd., Sheffield, and their associated Company, J. J. Saville & Co. Ltd., Sheffield. The various Cutanit grades and their applications are :—

1. Steel Cutting Grades

Grade S. Hard and wear-resisting—for finish-turning steel at high speeds with fine feeds on modern lathes.

Grade T. Tougher than Grade S—for rough machining under good conditions at medium speeds and with varying depths of cut.

Grade R. For rough machining all types of steel including castings, rough forgings, etc., at low or medium speeds with heavy and or interrupted cuts—will operate successfully at lower speeds or on old-type slower machine tools.

2. Cast-iron and Non-ferrous Cutting Grades

Grade I. For general machining of cast iron up to 200 Brinell, non-ferrous metals, wood, etc.—also for parts requiring high wear-resistance, such as lathe centres, gauges, measuring instruments and work rests.

Grade M. Tougher than Grade I—for planing cast iron and intermittent cutting at medium or low speeds and on old-type machine tools.

Grade O. Tougher than Grade M—for cutting, pressing, blanking, etc., where the tool is subjected to shock—for coal boring, percussive drilling, etc., and for machining materials such as graphite.

Grade SW. Extremely tough—for use under shock load, e.g., for swaging hammers.

3. Fine-finish Cutting Grades

Grade ICC. For machining cast iron above 200 Brinell, malleable iron, glass, china, stone and hard paper—for turning and rifling chill-cast iron, for fine finish-turning and boring, e.g., motorcar cylinders and for high speed finishing of cast iron.

Grade B. Harder than Grade ICC—for turning and rifling alloy chill-cast iron, for fine machining of plastics, also for button turning and drilling.

Recommended cutting conditions for Cutanit cemented carbides for various workpiece materials are given in table herewith.

MATERIAL	
GRADES OF STEEL.	
Steel Below 50 Tons Tensile.	
Black Stampings	.
Rough Forgings Removing Scale	.
Clean Metal	.
Steel 50-75 Tons Tensile.	
Black Stampings	.
Rough Forgings Removing Scale	.
Clean Metal	.
Nickel Chrome above 75 Tons Tensi	
Black Stampings	.
Rough Forgings Removing Scale	.
Clean Metal	.
Steel Castings	.
High-Speed Steel Annealed ...	.
Stainless Steel	
Castings	.
Bar	.
Manganese Steel 12% ...	.
GRADES OF CAST IRON	
Cast Iron below 200 Brinell	.
Cast Iron above 200 Brinell	.
Planing Cast Iron	.
Centrifugal Castings or Chromium Iron	.
Malleable Iron	.
10% Nickel Iron or Pearlite Iron	.
Chilled Cast Iron	.
NON-FERROUS MATERIALS	
Copper	.
Cupro Nickel, Soft Brass ...	.
Hard Brass, Cast Bronze, Gunmeta	
Aluminium	.
Aluminium Alloys, Zinc-Base Alloy	
NON-METALLIC MATERIALS	
Plastics, Erinoid, Hard Rubber	..
Glass, Slate	..
Marble	..
Porcelain	..
Wood	..
Compressed Paper	..
Granite	..
Graphitic Carbon	..

The figures given above must be ac
These data can be taken only as a g

OMMENDATIONS FOR CUTANIT

ROUGHING						FINISHING					
rade	Speed Ft. Min.	Feed In. Rev.	Depth of Cut (ins)	Clearance Degrees	Top Rake Degrees	Grade	Speed Ft. Min.	Feed In. Rev.	Depth of Cut In.	Clearance Degrees	Top Rake Degrees
R	200–250	.025–.04	¼–½	5–6	6–7	S or T	600–800	.005–.008	.015–.03	4–6	5–7
R.	200–250	.025–.04	¼–½	5–6	6–7	—	—	—	—	—	—
or T	250–350	.025–.04	¼–½	5–6	6–7	S or T	600–800	.005–.008	.015–.03	4–6	5–7
R	180–200	.025–.04	⅛–¼	5–6	4–6	S or T	600–800	.005–.008	.015–.03	4–6	4–6
R.	180–200	.025–.04	¼–½	5–6	4–6	—	—	—	—	—	—
or T	200–250	.025–.04	¼–½	4–6	5–7	S	600–800	.005–.008	.015–.03	4–6	6–8
R	120–160	.02	¼–½	4–6	0–4	S	250–500	.005–.008	.015–.03	4–6	4–6
R	120–160	.02	¼–½	4–6	0–4	S	250–500	.005–.008	.015–.03	4–6	4–6
or T	150–200	.02	¼–½	4–6	4–6	S	350–800	.005–.008	.015–.03	4–6	4–6
R	150–300	.02	¼–½	4–6	2–6	S or T	300–600	.005–.008	.01–.02	4–6	4–8
R.	100–200	.02	Up to ½	4–6	2–6	S	180–250	.003–.005	.01–.02	4–6	4–8
R.	70–100	.025–.04	⅛–¼	4–6	0–4	S or T	100–200	.003–.005	.015–.03	4–6	4–8
R.	20–200	.025–.04	⅛–¼	4–6	2–6	S or T	250–300	.003–.005	.015–.03	4–6	4–8
R.	50–70	.02	⅛–⅜	4–6	0–4	S	80–120	.005–.01	.01–.02	4–6	0–4
or M.	180–300	Up to .03	¼–½	5–7	4–6	or ICC	350–500	Up to .01	.015–.03	5–7	4–6
ICC.	60–200	Up to .03	¼–½	5–7	4–6	ICC	200–350	.005–.008	.015–.03	5–7	4–6
or O.	70–90	.062	½	3–5	–6 to –4	M	140–180	.015	.062	4–6	–6 to –4
r ICC	100–180	Up to .03	¼–½	5–7	4–6	ICC	200–300	.005–.008	.015–.03	5–7	4–6
r ICC	100–200	.01 to .03	¼–½	5–7	4–6	ICC	200–350	.005–.008	.015–.03	5–7	4–6
l.	20–50	.008–.01	Up to ⅛	4–6	–2 to 0	or ICC	40–70	.004–.006	.01–.02	4–6	–2 to 0
CC.	15–20	Up to .08	Up to ½	2–4	–3 to 0	ICC or B	20–35	.006–.01	.01–.02	2–4	–3 to 0
l.	500–800	.03	⅛	5–6	10–20	I	750–1000	Up to .01	.01–.02	5–6	15–30
l.	200–500	.02	⅛	5–6	5–8	I	300–600	.012	.01–.02	4–6	5–8
l.	400–600	.015–.02	⅛	4–5	0–5	I	500–1000	.01	.01–.02	4–6	0–5
l.	up to 2000	.01 to .02	Up to ½	5–6	15–25	or ICC	Unlimited	.004	.01–.02	5–7	15–25
l.	300–600	.015–.02	⅛	4–6	15–25	or ICC	500–900	.004	.01–.02	4–6	15–25
ICC	400–600	.006	⅛–1/16	8	8–10	B	600–800	.003	.01–.02	8	8–10
l.	60–90	Hand feed	—	4	0–3	ICC	80–100	Hand feed	.003	4	0–3
l.	80–120	recom-	—	4	0–3	ICC	100–120	recom-	.003	4	0–3
l.	20–30	mended	—	4	–3	ICC	30–50	mended	.003	4	–3
or M	1500–3000	.1	⅛	8	45	I	Unlimited	.1	.08	8	45
or M	1000–2000	.05	⅛	8	30	ICC	1500–3000	.05	.06	8	30
ICC.	20–25	.05	⅛–⅜	6	–3–0	ICC	25–30	.04	.04	5	–3 to 0
O	300–400	.005–.01	⅛–1	6	18–25	O	400–500	.002	.01–.2	5	18–25

d to effect a compromise between the power needed for the cut, the economic tool life, the speed and the feed used.
and applied in accordance with the power available, the condition of the machine tool and all other working conditions.

TABLE V.—RATE OF FEED AND DEPTH OF CUT FOR CUTANIT TOOLS

Material	Feed Ins.	Depth of Cut Ins.
Steel :		
Mild Steel—28 tons tensile	0·012–0·04	0·06–0·4
35 ,, ,, ...	0·012–0·04	0·06–0·4
41 ,, ,, ...	0·012–0·04	0·08–0·4
48 ,, ,, ...	0·010–0·04	0·08–0·4
54 ,, ,, ...	0·010–0·04	0·08–0·4
Chrome Nickel Steel		
64 tons tensile	0·008–0·04	0·08–0·4
68–92 ,, ,, ...	0·008–0·032	0·099–0·4
95–012 ,, ,, ...	0·008–0·032	0·099–0·4
Steel Castings—32–64 tons tensile ..	0·008–0·06	0·08–0·4
Manganese Steel (12-14% Manganese)	0·008–0·02	0·08–0·4
Cast Iron—Up to 200 Brinell	0·012–0·06	0·08–0·4
Over 200 Brinell and Chilled Iron	0·012–0·06	0·08–0·4

KENNAMETAL.—This is marketed by George H. Alexander Machinery, Ltd., Coleshill Street, Birmingham, 4, and is available in four grades, having the following characteristics and applications :—

Grade K3H.—This has a hardness of 92 Rockwell A and is for finishing or moderate cuts on carbon or alloy steels of 0·3 per cent carbon ; also for general use on soft steels containing less than 0·3 per cent carbon. It is also used for precision boring of steel where 0·004-inch feed or greater is employed, and for the milling of steel.

Grade K4H.—This has a hardness of 92·3 Rockwell A and is for very light cuts on steel, and for precision boring with less than 0·004-inch feed. It is recommended for tools having a large nose radius, or where the tool must dwell without cutting. It is used for milling or very rough cutting of brass, bronze, and aluminium alloys.

Grade KM.—A crater-resistant grade for roughing cuts on carbon and alloy steel forgings, bar stock, tubing, etc., having a carbon content of 0·30 per cent and greater. It is also recommended for the milling of steel where heavy chip loads are encountered, and for planing and shaping.

Grade K6.—This has a hardness of 92·2 Rockwell A, is very abrasion resistant and is recommended for general use on cast iron, brass, bronze, and aluminium alloys. It is also useful for non-metallic materials.

The makers of Kennametal recommend that the speeds, feeds and depths of cut be in accordance with the ranges set out in Table VI, which represent average good practice. The higher speeds here given apply, in general, to the lighter cuts, and the lower speeds to the heavier cuts. Cutting for this brand of carbide, arranged in order of economy are given in Table VII, while speeds for steel cutting are shown in Table VIII.

TABLE VI.—TYPICAL SPEEDS, FEEDS AND DEPTHS OF CUT FOR KENNAMETAL CARBIDE TOOLS

Material Machined—Straight Cutting	Speed Feet per Minute	Feed Inches per Revolution	Depth of Cut, Inches
Aluminium, Die-Cast (94 Al ; 6 Si)	1400 to 3500	0·002 to 0·020	0·062 to 0·125
Beryllium Bronze, Hardened	150 to 300	0·008 to 0·040	up to $\frac{3}{8}$
Brass, Common Yellow ..	300 to 1000	0·008 to 0·040	up to $1\frac{1}{4}$
Grey Cast Iron up to Rockwell 16 C	165 to 400	0·040 to 0·080	0·040 to $\frac{3}{8}$
Grey Cast Iron, 16 to 43 Rockwell C	130 to 260	0·008 to 0·080	0·040 to $\frac{3}{8}$
Cast Iron, Malleable ..	250 to 400	0·008 to 0·080	0·040 to $\frac{1}{2}$
Cast Iron, Copper Silicon	175 to 350	0·008 to 0·070	0·040 to $\frac{3}{8}$
Chilled Cast Iron, 56 Rockwell C	15 to 40	0·125 to 0·320	0·040 to $\frac{3}{16}$
Armature Copper	800 to 1200	0·008 to 0·040	0·008 to $\frac{1}{4}$
Electrode Carbon	150 to 300	0·020 to $\frac{3}{8}$	0·040 to $1\frac{1}{2}$
Bakelite, Durez, etc. ..	600 to 1000	0·012 to 0·050	0·004 to $\frac{1}{4}$
Paper Calendar Rolls ..	300 to 800	0·012 to 0·050	0·008 to $\frac{1}{4}$
Steel, Soft 0·15 Carbon..	200 to 1000	0·008 to 0·040	0·003 to $\frac{1}{2}$
Steel, about 14 Rockwell C	200 to 1000	0·008 to 0·040	0·003 to $\frac{1}{2}$
Steel, about 25 Rockwell C	175 to 600	0·008 to 0·040	0·003 to $\frac{1}{2}$
Steel, Rockwell 38 C Chrome Vanadium ..	175 to 300	0·008 to 0·040	0·003 to $\frac{1}{4}$
Steel, Cast, 0·60 C, 0·60 Mn	175 to 300	0·010 to 0·040	0·050 to $\frac{3}{8}$
Steel, Stainless, 48 Rockwell C	175 to 400	0·004 to 0·040	0·003 to $\frac{1}{4}$
Steel, Stainless 18–8 ..	125 to 400	0·004 to 0·040	0·003 to $\frac{1}{4}$
Steel, Nickel Chrome Molybdenum, 35 Rockwell C	100 to 200	0·004 to 0·025	0·003 to $\frac{1}{4}$
Steel, 0·50 C, 0·80 Mn, 0·60 Mo, 49 Rockwell C ..	85 to 125	0·004 to 0·040	0·003 to $\frac{1}{8}$
Steel, 2·50 Mn, 0·45 C ..	100 to 175	0·004 to 0·040	0·003 to $\frac{3}{16}$

TABLE VII.—SPEEDS FOR STEEL CUTTING

Hardness of Work			Preferred Speed
Rock. C.	Brinell	Scler.	Surface ft. per min.
65	682	93	20 to 30
60	601	83	30 to 50
55	545	75	50 to 60
51	495	69	60 to 80
45	427	62	80 to 100
40	370	54	100 to 150
35	323	46	150 to 220
30	276	42	200 to 300
25	249	38	300 to 400

TABLE VIII.—CUTTING SPEEDS FOR KENNAMETAL.
Arranged in Order of Economy.

Workpiece Material	State of Metal	Recommended Speed— Feet per min.
Steel—0·45 Carbon ..	As forged	220 to 400
,, 0·45 Carbon ..	Hardened	150 to 300
,, 0·45 Carbon ..	As cast	220 to 300
,, 0·35 Carbon ..	As cast	220 to 300
,, 0·90 Carbon ..	Annealed bars	200 to 300
Nickel Chrome Steel ..	Forged	200 to 300
,, ,, ,, ..	33 to 40 Rockwell C ..	120 to 220
Nickel Chrome and Nickel Chrome Molybdenum ..	33 to 40 Rockwell C ..	120 to 220
Chromium Steel	As forged and annealed	200 to 300
,, ,, ...	45 Rockwell C	80 to 100
,, ,, ...	63 Rockwell C	20 to 30
18–8 Stainless	Cast	150 to 200
14 per cent Chromium bars	—	180 to 250
High Speed Steels ..	Annealed	120 to 220
Monel metal K	Hardened	70 to 90
,, ,, S	Hardened	70 to 90
Malleable Iron	Cast	400 to 600
Copper Alloy Iron ..	Cast	200 to 300
Aluminium Silicon ..	Cast	500 to 1000
Brass Yellow	Cast	500 to 1000

MITIA.—This brand of carbide is made by Firth Brown Tools, Ltd., Carlisle St., Sheffield, in nine standard grades, having the characteristics as follows :—

Grade A.—A tough grade for use where the rigidity usually demanded for carbide tools cannot be obtained. Will withstand severe intermittent cutting.

Grade B.—A general-purpose grade suitable for most operations on cast iron, non-ferrous metals and non-metallic materials such as plastics, etc.

Grade C.—A very hard grade for use on chilled iron rolls and very abrasive non-metallic composition such as glass, pottery, synthetic substances, etc. and for fine cuts on cast iron, aluminium and aluminium alloys.

Grade D1.—A grade normally used for wear-resistant parts, for example micrometer anvils, centreless-grinder work rests, drawing and extruding dies, etc.

Grade TA5.—A heavy-duty grade for the rough machining of steel under bad conditions, particularly rough forgings and castings. Will readily machine at relatively low speeds and heavy feeds.

Grade TA.—A general-purpose grade for machining under reasonably good conditions. It is particularly suitable for machining alloy steels, as distinct from mild steels.

Grade TE10.—Also a general-purpose grade for machining steel. Particularly suitable for machining mild steels or low alloy steels, it makes a useful semi-finishing tool and can be employed for rough machining clean bars. Conditions for its use should be slightly better than those employed for TA.

TABLE IX.—RECOMMENDATIONS FOR PERPRO (CAST IRON, NON-FERROUS METALS AND PLASTICS)

Workpiece Material	Grade	Rough Turning			Finish Turning		
		Surface Speed Ft. per Min.	Top Rake Deg.	Feed Ins. per Rev.	Surface Speed Ft. per Min.	Top Rake Deg.	Feed Ins. per Rev.
Cast Iron ..	AS	185–200	3–5	0·100	250–300	3–5	Up to 0·010
Close Grain Iron	AS or AU	160–200	3	0·050	200–250	3–5	0·008
Chromium Iron	AS	130–180	3	0·010	200–250	3–5	0·005
Malleable Iron..	AS or AU	165–210	5	0·030	250–300	3–5	0·008
Pearlitic Iron ..	AU	20– 30	0–2 neg.	0·008–0·010	25–45	0	0·004
Copper	AS	500–800	15–25	1/32	750–1000	15–25	Up to 0·012
Cupro-Nickel ..	AS or AU	350–500	8	0·020	400–600	8	Up to 0·012
Soft Brass ..	AS	750–1000	3	1/32	750–1000	3	Up to 0·015
Hard Cast Brass	AU	400–600	3	0·020	500–800	3	Up to 0·012
Bronze	AS or AU	400–600	3	0·020	500–800	3	0·012
Gun Metal ..	AS or AU	400–600	3	0·015–0·020	500–800	3	0·012
Aluminium Bronze ..	AS or AU	350–500	3	0·012–0·018	400–550	3	0·010
Admiralty Bronze ..	AS or AU	400–600	3	0·015–0·020	500–800	3	0·012
Manganese Bronze ..	AS or AU	350–400	3	0·012–0·018	350–500	3	0·010
Aluminium ..	PD	Up to 7000	10–15	0·012	Up to 7000	Up to 15	0·004
Silicon Aluminium ..	PD	400–550	8–10	0·008	500–750	8–10	0·004
Aluminium Alloys ..	PD	500–800	10	0·008	700–1000	10	0·005
Zinc Base Alloys	AS	600–800	13	0·005	800–1000	13	0·003
Duralumin ..	PD	600–800	13	0·012	800–1000	13	0·005
Plastics ..	AS or AU	300–600	0–8	0·006	300–600	0–8	0·003
Erinoid	AS or AU	300–600	0–8	0·006	300–600	0–8	0·003
Ebonite ..	AS or AU	200–500	0	0·006	200–500	0	0·003

Grade TE.—An extremely hard and wear-resistant grade. It is designed for finish-turning mild and low alloy steels. Conditions should be good. Very high speeds with fine feeds will give the best results.

Grade TE5.—An extremely hard and wear-resistant grade for the finished turning of high tensile high alloy steels. Conditions should be good and where chipping occurs, a negative top-rake angle should be tried. High speeds with fine feeds are recommended.

PERPRO.—This brand of carbide is manufactured by the Production Tool Alloy Co., Ltd., Harlington Works, Sharpenhoe, Beds. Several grades are available. The recommended grades for various cutting conditions and workpiece materials are set forth in Tables IX and X.

PROLITE.—This is made by Protolite, Ltd., a subsidiary company of Murex, Ltd., Rainham, Essex, in nine grades, having the properties as follows :—

Grade 15A.—This is a general-purpose carbide for cast iron, malleable iron and non-ferrous metals.

Grade 21A.—A type of carbide for cutting chilled iron and for the shock-free machining of abrasive materials such as light alloys, plastic and non-metals.

Grade 1C.—This is for light cuts, such as reaming operations. It is a harder grade than 21A, and should not be used where vibration is present.

Grade 3R.—A grade for planing tools and rough working conditions.

Grade 6W.—A variety for general use in cutting at high speed under good conditions.

Grade 14K.—This is used for all classes of steel, in particular for finishing operations at high speeds and light cuts.

Grade 8K.—For machining nickel-chrome and other steels above about 50-ton tensile.

Grade 2W.—For heavy cuts on steel, including work involving intermittent cutting at slower speeds.

Grade 4T.—This is a special grade for cutting steel. It has been developed for machining high-tensile and other steels which present unusual difficulties with normal grades.

Recommendations of speeds, feeds and tool angles for turning with are given in Table XI.

TABLE X.—RECOMMENDATIONS FOR PERPRO (STEEL CUTTING)

Grade of Steel	Grade	Rough Turning			Finish Turning		
		Surface Speed Ft. per min.	Top Rake Deg.	Feed Ins. per Rev.	Surface Speed Ft. per min.	Top Rake Deg.	Feed Ins. per Rev.
Up to 35 Tons Tensile Castings	PC	150–200	8	0·050	180–250	8–10	0·004–0·006
	PA	200–250	8	0·030	250–350	8	0·004–0·006
	PB	250–300	Up to 6	0·010	300–350	8–10	0·004–0·006
Rough Forgings and Black Bar	PC	150–200	8	0·080	180–250	8–10	0·010–0·006
	PA	250–300	8	0·040	300–350	8–10	0·008–0·006
	PB	350–400	Up to 8	0·010	350–400	8–10	0·008–0·006
Clean Stock	PC	200–250	Up to 10	0·080	250–300	8	0·010–0·006
	PA	250–300	10	0·040	350–400	8–10	0·008–0·006
	PB	300–400	8–10	0·012	450–500	8–10	0·005–0·006
35–50 Tons Tensile Castings	PC	120–180	8	0·040	150–200	8	0·008–0·010
	PA	180–220	8	0·028	220–300	8	0·008–0·010
	PB	250–350	5	0·010	300–400	8	0·004–0·006
Rough Forgings and Black Bar	PC	120–150	10	0·050	135–190	8–10	0·008–0·010
	PA	200–250	8	0·040	250–300	8–10	0·008–0·010
	PB	250–350	5	0·010	300–450	8–10	0·008–0·010
Clean Stock	PC	150–200	8–10	0·050	180–220	8–10	0·008–0·010
	PA	200–300	8	0·030	250–300	8–10	0·008–0·010
	PB	300–450	5	0·010	350–450	10	0·008–0·010
50–65 Tons Tensile Rough Forgings and Black Bar	PC	70–100	8	0·032	100–150	10	0·008
	PA	120–150	8	0·015	200–250	8	0·008
	PB	170–250	5	0·008	250–300	5–10	0·008
Clean Stock	PC	80–120	10	0·030	120–150	10	0·010
	PA	120–180	8	0·010	160–220	8	0·008
	PB	180–250	5	0·008	250–300	8	0·005
65 Ton Tensile and Over Rough Forgings	PC	60– 90	10	0·010	90–100	8	0·010
	PA	80–100	5	0·008	100–200	5–8	0·008
					200–250	5–8	0·005
Clean Stock	PC	100–120	10	0·030	120–140	8–10	0·010
	PA	110–150	5	0·018	150–210	8	0·008
	PB	150–200	3	0·009	200–250	5–8	0·003
Manganese Steel	PC	10– 20	8	0·020	20– 30	8	0·010
	PA	10– 25	3	0·010	23– 30	3	0·005
Wrought Iron	PA	200–300	5	0·030	300–400	8	0·010
Stainless Steel Castings	PC	50– 90	10	0·025	90–110	10	0·015
	PA	65–100	8	0·015	100–180	8	0·008
	PB	90–125	3	0·008	125–200	5–8	0·005

TABLE XI.—RECOMMENDATIONS FOR PROLITE

Workpiece Material	Clearance Deg.	Rough Turning			Finish Turning		
		Speed Ft. per Min.	Feed	Top Rake Deg.	Speed Ft. per Min.	Feed	Top Rake Deg.
Ferrous Metals							
Cast Iron—180 to 250 Brinell	4–6	180–220	Up to 0·020	3	350–500	Up to 0·010	3
Cast Iron—250 to 400 Brinell	4–6	160–200	0·012	3	200–300	0·008	3
Cast Iron—High Silicon	4–6	60–100	0·012	3	120–180	0·008	3
Chilled Iron Rolls	2–4	15– 20	0·080	0	20– 40	0·040	0
Wrought Iron	4–6	250–350	0·012	3	350–500	0·008	8
Malleable Iron	4–6	160–200	0·012	8	200–400	0·008	8
Pearlite Iron	4–6	20– 35	0·010	0	30– 60	0·004	0
Manganese Steel, 12%	4–6	10– 30	0·020	3	35– 60	0·010	3
Chrome Vanadium Steel : 65 tons per sq. in.	4–6	80–120	0·012	8	150–200	0·008	8
Nickel Chrome Steel :—							
55 tons per sq. in.	4–6	150–200	0·015	3	200–400	0·008	8
70 tons per sq. in.	4–6	110–150	0·015	3	160–200	0·008	8
90 tons per sq. in.	4–6	90–120	0·020	3	120–150	0·010	8
Carbon Steel :—							
25–35 tons per sq. in.	4–6	350–600	0·030	8	600–800	0·015	8
35–45 tons per sq. in.	4–6	300–400	0·025	8	400–600	0·012	8
45–55 tons per sq. in.	4–6	250–350	0·020	8	350–500	0·010	8
55–65 tons per sq. in.	4–6	200–300	0·015	8	300–450	0·008	8
Non-Ferrous Metals							
Aluminium	4–6	to 3000	0·012	15–20	to 6000	0·006	20–25
Silicon Aluminium	4–6	500–650	0·012	10–15	650–800	0·006	15–20
Aluminium Alloys	4–6	500–800	0·010	10–15	800–1000	0·004	15–20
Cast Brass	4–6	400–600	0·020	3	500–800	0·012	3
Soft Brass	4–6	500–700	0·020	3	700–1000	0·012	3
Bronze	4–6	400–600	0·020	3	500–800	0·012	3
Gunmetal	4–6	400–600	0·020	3	500–800	0·012	3
Copper	4–6	500–800	0·030	10–15	800–1000	0·012	15–25
Copper, Electrolytic	4–6	500–800	0·030	10–15	800–1000	0·012	15–25
Duralumin	4–6	600–800	0·030	10–15	800–1000	0·012	15–20
Phosphor Bronze	4–6	500–700	0·020	3	700–1000	0·012	3
Silumin	4–6	400–500	0·020	15	500–600	0·008	15
Non-Metals							
Amorphous Carbon	4–6	200–250	0·010	15	250–350	0·005	15
Compressed Paper	4–6	450–600	0·030	25	600–800	0·020	25
Glass	4–6	60– 80	Use	0	80–100	Use	0
Porcelain	4–6	30– 40	Hand	0	40– 50	Hand	0
Marble	4–6	60– 90	Feed	0	90–120	Feed	0
Granite	4–6	10– 25	0·030	0	25– 40	0·030	0
Plastics (Bakelite, Ebonite, etc.)	15	300–600	0·006	0	600–800	0·003	0
Graphite	4–6	maximum	0·006	8	maximum	0·003	8
Hard Rubber	15	300–600	0·006	3	600–800	0·003	3
Wood	4–6	maximum	0·100	45	maximum	0·100	45

TABLE XII.—RECOMMENDATIONS FOR "SX" TUNGSTEN-CARBIDE

Workpiece Material	Rough Turning			Finish Turning		
	Speed Ft. per Min.	Tool Angles		Speed Ft. per Min.	Tool Angles	
		Clearance Deg.	Top Rake Deg.		Clearance Deg.	Top Rake Deg.
Grades of Steel						
28–35 Tons tensile—						
Black bar, stampings ..	500–600	5		1000–1500		
Rough forgings—						
Removing scale ..	350–400	5	6–7	—	5–6	5
Clean metal	600–1000	5		1000–1500		
Castings	300–400	5		500–750		
35–45 Tons tensile—						
Black bar, stampings ..	450–550	5		1000–1200		
Rough forgings—						
Removing scale ..	300–400	5	5–6	—	5–6	5
Clean metal	600–750	5		1000–1200		
Castings	250–350	5		400–500		
40–45 Tons tensile—						
Black bar, stampings ..	300–400	5		800–1000		
Rough forgings—						
Removing scale.. ..	250–350	5	4–5	—	5–6	5
Clean metal	500–600	5		800–1000		
Castings	200–300	5		300–400		
55–65 Tons tensile—						
Black bar, stampings ..	250–350	5		600–800		
Rough forgings—						
Removing scale ..	225–300	5	4–5	—	5–6	4–5
Clean metal	450–550	5		600–800		
High-speed steel—						
Annealed	100–200	4		200–300		
Chrome nickel—65/90 tons tensile—						
Black bar, stampings ..	120–200	4		250–400		
Forgings	120–200	4	3–4	250–400	4–5	3–4
Clean metal	250–400	4		250–500		
Stainless steel—						
Castings	70–100	4		100–150		
Bar	150–250	4	3–4	250–300	4–5	3–4
Manganese steel—						
12 per cent.	10–25	4		25–50		
Cast Iron and Non-Ferrous Materials						
Cast-iron—200 Brinell	180–220	5	8	350–450	5	3
Close-grained iron.. ..	160–200	5	5–8	250–350	5	3
Centrifugal castings ..	120–160	5	3–5	250–350	5	3
Chromium iron	120–160	5	3–5	200–250	5	3
Malleable iron	180–220	5	8	350–450	5	3–5
10 per cent nickel iron ..	20– 30	4	0	25– 45	4	0
Pearlite iron	20– 30	4	0	25– 45	4	0
Wrought iron	300–400	5	8	400–600	5	8
Chilled iron rolls	15– 20	4	0	20– 35	4	0
Copper	500–800	5–6	15	750–1000	5	13
Cupro nickel	350–500	5	8	400–600	5	8

(*Table continued on next page*)

TABLE XII. (*continued*)—RECOMMENDATIONS FOR "SX" TUNGSTEN-CARBIDE

Workpiece Material	Rough Turning			Finish Turning		
	Speed Ft. per Min.	Tool Angles		Speed Ft. per Min.	Tool Angles	
Cast Iron and Non-Ferrous Materials—*contd.*		Clearance Deg.	Top Rake Deg.		Clearance Deg.	Top Rake Deg.
Soft brass	750–900	5	3	750–1000	5	3
Hard cast brass	400–600	4	3	500–800	5	3
Bronze	400–600	4	3	500–800	5	3
Gunmetal	400–600	4	3	500–800	5	3
Aluminium bronze	300–450	4	3	400–600	4	3
Admiralty bronze	300–450	4	3	400–600	4	3
Manganese bronze	300–450	4	3	400–600	4	3
Aluminium	1000–2000	5–6	15	Any speed above 1000	5	15
Silicon aluminium	400–600	4–5	15	500–750	4–5	15
Aluminium alloys	600–800	5	15	750–900	5	15
Zinc-base alloys	600–800	5	15	750–900	5	15
Duralumin	600–800	5	15	750–900	5	15
Plastics	400–600	20–25	3 Neg.	800–1000	20–25	3 Neg.
Erinoid	400–600	20–25	3 Neg.	800–1000	20–25	3 Neg.
Hard rubber	600–800	20–25	3 Neg.	800–1500	20–25	3 Neg.
Porcelain	20– 30	4	3 Neg.	30– 50	4	3 Neg.
Glass	60– 90	4	5–8	80–100	4	3
Slate	80–120	4	3	100–120	4	3
Marble	80–120	4	3	100–120	4	3

"SX" Tungsten Carbide.—This brand of carbide is marketed by Buck and Hickman, Ltd., 2, Whitechapel Road, London, E.1. It is available in seven grades, A, B, C, D, E, F, and G, having the following applications. A—for cast iron, non-ferrous materials and general use; B—for chilled-iron rolls and abrasive materials; C—for aluminium and certain classes of steel; D—for machining steels at high speeds; E—for machining steels at medium speeds; F—for machining steels at low speeds; and G—for planing and wood-working tools. The speeds and tool angles recommended by the makers for this cutting material are set out in Table XII.

VERALOY.—This is manufactured by Veraloy Products, Ltd., Beech Rd., The Marsh, High Wycombe, Bucks., who recommend the tool angles and cutting conditions given in Table XIII.

TABLE XIII.—RECOMMENDED CUTTING CONDITIONS FOR VERALOY

Material	Clearance Deg.	Top Rake Deg.	Speed Ft. per Min.		Feed Ins. per Rev.	
			Roughing	Finishing	Roughing	Finishing
STEELS					Up to	Up to
Manganese Steel ..	5	3	10– 25	25– 65	0·020	0·010
Steels above 75 tons tensile	5	8	100–150	175–300	0·020	0·010
Steels 50–75 tons tensile	5	8	150–200	200–400	0·025	0·010
Steels below 50 tons tensile	5	8	200–300	200–400	0·025	0·010
CAST IRON						
Cast Iron below 200 Brinell	5	8	175–225	300–450	0·020	0·010
Cast Iron from 200-400 Brinell ..	5	8	150–200	200–300	0·012	0·008
Malleable Iron ..	5	8	100–150	150–300	0·012	0·008
Chilled Cast Iron ..	0–3	0	15– 20	20– 40	0·080	0·040
NON-FERROUS MATERIALS						
Copper	5	15–25	500–750	750–1000	0·030	0·015
Hard Brass, Bronze, Gunmetal ..	5	3	400–600	500–800	0·020	0·015
Aluminium ..	5	15–25	600–1000	over 1000	0·020	0·012
Aluminium Alloys, Zinc Alloys ..	5	15–25	300–500	500–900	0·020	0·012
NON-METALLIC MATERIALS						
Plastics	15	0	200–400	200–400	0·008	0·005
Glass	5	0	50–100	75–100	} Hand Feed	
Porcelain	5	0	25– 50	25– 50		
Marble	5	0	50– 80	50– 80		
					Up to	Up to
Granite	5	0	10– 25	25– 30	0·030	0·030
Graphite	5	8	300–400	Maxi'm	0·008	0·004
Compressed Paper	5	25	400–600	600–800	0·030	0·020
Wood	5	45	Maxi'm	Maxi'm	0·100	0·100

TABLE XIV.—WARDITE CUTTING SPEEDS AND ANGLES

Material	Roughing				Finishing			
	Speed Ft. per Min.	Feed Inch per Rev.	Depth of cut Inches	Top Rake rough cut Deg.	Speed Ft. per Min.	Feed Inch per Rev.	Depth of cut Inches	Top Rake finish cut Deg.
Cast Iron	160–200	0·012–0·025	0·375	0–2	250–400	0·006–0·010	0·020–0·040	0–4
Chilled Cast Iron	18–20	0·050–0·060	0·375	0 to –4	25–30	0·005	0·015–0·020	0 to –4
Steel below 50 tons tensile	180–200	0·030	0·5	4–6	800	0·005	0·030–0·040	6–8
Steel above 75 tons tensile	140–160	0·020	0·25	4–6	400–500	0·004	0·020–0·030	6–8
Aluminium Alloy and Zinc-base Alloy	400	0·020–0·030	0·25–0·30	According to hardness of Alloy 8–25	750–800	0·004	0·020	According to hardness of Alloy 8–25
Hard Brasses, etc., Gunmetal ..	500	0·010–0·020	0·20–0·25	2–4	700	0·010	0·010–0·020	2–4

Wardite.—This material which is manufactured by Thos. W. Ward, Ltd., Albion Works, Sheffield, is supplied in grades which may be classified into two groups. Those of the first group are suitable for all materials other than steels; the second group have been specially produced for steel cutting. The grades are as follows: FW—for cast iron, non-ferrous metals, plastics; roughing intermittent cuts and most machining operations: FE—machining chilled-cast rolls, reboring cylinders. MS—wood cutting. FR.—for stone and coal drill bits. GM.—all grades of steel, roughing and finishing; mild and alloy steels. HV.—for finishing steels at very high turning speeds, using light cuts and small feeds. The maker's recommendations are as shown above in Table XIV.

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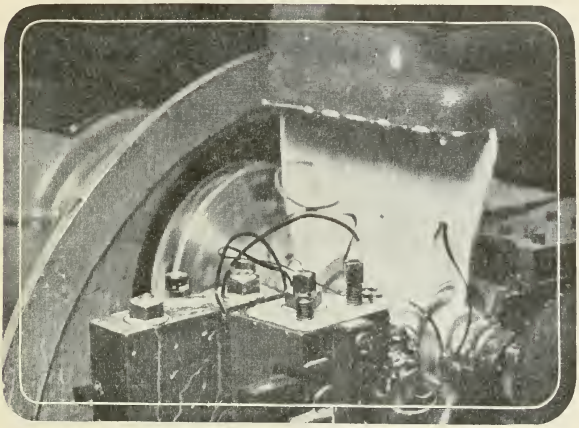

AFTER apologies for the alliteration, coolants do have quite a place in a textbook dealing with cemented carbide tools. Whilst this class of tool alloy is particularly resistant to loss of cutting edge at high temperatures and exceptional surface speeds, a coolant confers distinct advantages when dealing with malleable iron, carbon steels, and aluminium.

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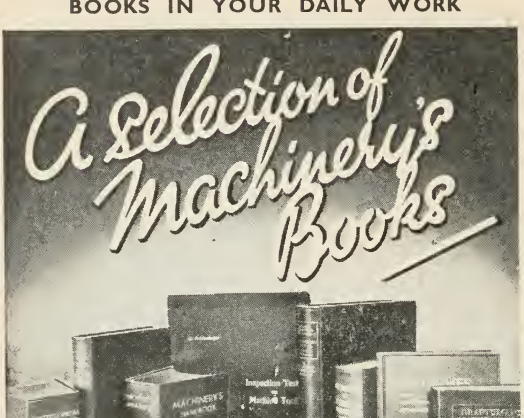

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